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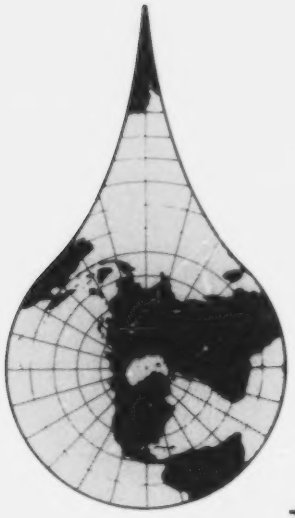

Flexible Structures:

Reference Manual on Design

U.S./U.S.S.R. Joint Studies on Plastic Films and Soil Stabilizers

U.S.S.R. MINISTRY OF RECLAMATION AND WATER MANAGEMENT

All-Union Scientific-Industrial Association for Polymer Application in Reclamation and Water Management

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This report covers one of several joint studies carried out as part of a U.S./U.S.S.R. team for Joint Study in **Plastic Films and Soil Stabilizers** on the subject field of *Plastics in Hydrotechnical Construction* (U.S. Project No. 01.120401 — U.S.S.R. Project Categories 11-3-1 and 11-3-2). This was done under the **U.S./U.S.S.R. Joint Working Group on Plastics in Hydrotechnical Construction**, by the *Joint Commission on the Soviet American Scientific and Technical Cooperation Program*. The report covers the design concepts for the use of flexible membranes for flexible and inflatable structures, for hydraulic structures, such as cofferdams, diversion dams, baffle walls, and drop structures. A Russian-English glossary for the subject is included as an appendix.

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A WATER RESOURCES TECHNICAL PUBLICATION

A Joint Effort of
U.S./U.S.S.R. Team in
Plastic Films and Soil Stabilizers

December 18, 1986

UNITED STATES DEPARTMENT OF THE INTERIOR
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PREFACE

This report covers one of several joint studies carried out as part of a **U.S./Joint Working Group on Plastic Films and Soil Stabilizers in the Field of Plastics in Hydrotechnical Construction** (U.S. Project No. 01.120401 — U.S.S.R. Project Categories II-3-1 and II-3-2). This was done under the U.S./U.S.S.R. Working Group Program for **Water Resources** under the Soviet-American Joint Commission on **Scientific and Technical Cooperation Program.** The joint studies were done in the period 1975-82. Overall program objectives and major technical work guidelines were developed prior to 1975 by the U.S./U.S.S.R. Joint Working Group on Plastics in Hydrotechnical Construction Program under the leadership of H.G. Arthur, U.S. Chairman, and P. G. Sviklis, U.S.S.R. Chairman for this working group. The goals and objectives of these joint studies were the development of new technical knowledge in this field beyond that of either participating country. This has required the careful cooperation of many scientists and engineers in each country. The technical programs were coordinated by:

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This report covers the design concepts for the use of flexible membranes for flexible and inflatable structures for hydraulic structures such as cofferdams, diversion dams, baffle walls, and drop structures. A Russian-English glossary for this subject is included as an appendix.

The report and materials for the *Glossary on Flexible Structures* were prepared in the U.S.S.R. by a team from the Southern Scientific Research Institute of Hydraulic Engineering and Reclamation (IuzhNIIGiM) under the direction of Professor B.I. Sergeev, Doctor of Applied Sciences.

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This report was prepared in the U.S.S.R. as part of the joint study. During the translation, in the U.S.A., it was discovered that a few explanatory terms in some tables and in the text were uncertain and some numeric and mathematical operator errors exist in the report. It is not possible now to clear up these errors and uncertainties. Because the greater part of the report is felt to be of value to engineers in the field of study, the report is being issued as is. The informed reader no doubt will be able to accommodate to these few uncertainties.

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Denver, Colorado
December 1986

GENERAL INFORMATION ON FLEXIBLE STRUCTURES

DESIGNATION AND RANGE OF USE

Characteristic aspects of building hydraulic structures are a protracted construction period and higher cost per unit of finished production as compared with other branches of industry. This fact necessitates a daily struggle to utilize labor, materials, and monetary funds most effectively, simplify structural designs, reduce transportation costs, and shorten construction times to the maximum extent. Using new construction materials, shortening construction times, reducing expenditures for transporting materials, and cutting down on the amount of materials and worker hours involved will improve the return on capital investments, accelerate the rates of economic development, and result in reduced expenditures per unit of production and a more rapid payback on investments.

The impressive development of hydrotechnical construction over the last century has taken place almost entirely along the path of creating and improving structures made of rigid materials: metal, concrete, rock, and wood. The distinctive feature of these materials consists in the combination of high strength with great rigidity. This quality, necessary for normal operation of the majority of structures, has had negative effects, thus in a number of cases, prohibiting the design of structures having minimal weight. Rigid structures—which will be referred in this text as structures made of traditional materials—usually have the same volume whether in operation or not, and so transporting them often becomes difficult.

It is interesting to note the tendency of systems to improve with respect to function, both in the evolution of living things and in the development of hydraulic construction (from simple to complex and from angular to streamlined).

The study of this tendency in nature can offer much in the way of enhancing the performance of traditional hydraulic structures now in operation and designing new lightweight architectural forms with greater spans. It will help to:

- Improve existing structures and to introduce new technical advances
- Achieve industrialization of production on the basis of unification, standardization, and prefabrication of component parts
- Create construction materials with new effective properties
- Improve experimental design methods on physical models

All natural forms are characterized by the following:

- An absence of abrupt transitions (of a vertical form to a horizontal) that would give rise to additional stresses
- Rational utilization of materials
- Gradual reduction in the mass of the structure from the center or central axis toward the periphery
- Distribution of strong material along principal stress lines
- Tendency to form elongated, flexible structures having small cross sections
- Polarization of stresses and their mutual neutralization
- The principle of turgidity, etc.

The structural logic of natural forms is especially well manifested in this. The application of natural principles has been observed recently even in the design of concrete and reinforced concrete structures. Here, the tendency is toward a simpler form (configuration) and minimal surface, and avoidance of exterior and interior angles, sharp edges, protrusions and ridges, and abrupt cross-sectional transitions. The opinion is that a concrete surface must be smooth; in a zone where cavitation phenomena are present, reinforcement projections and bumps caused by aggregate are unacceptable.

Planar, spatial, corrugated, and guyed structures, in which the load carrying capacity is a function of their geometric shape, are widespread throughout nature. Geometric shape, in turn, can be variable and constant.

For instance, the cranium of animals, tortoise shell, nutshells, eggs, and mollusk shells are all different and permanently shaped natural casings whose median surface is a Gauss convex curvature surface. But the requirement not to change shape is not always imposed on natural casings. On the contrary, in plants which cannot move about in space, different parts of the organism are constructed (from the geometric viewpoint) as casings with a median surface represented by Gauss concave curvature.

The Gauss concave curvature surface allows change in shape without deformation being subject to flexure alone.

This property is widely used, for instance, by plant leaves and cuttings. Leaves must follow the sun to receive the maximum amount of energy.

Leaves of the lilac often take the shape of a hyperbolic paraboloid; and moreover, they are divided into two halves with each half being capable of flexing independently of the other. The leaf of the burdock (*Arctia*) has the shape of a surface consisting of several conoidal surfaces. Because of this, its large surface is not ruptured by wind pressure and it is able to flex and regain its shape. Of especial interest are inflatable, pneumatically and hydraulically stretched systems (scallop squash, tomatoes, blood vessels, sea anemones, etc.) in which there are practically no reinforcement tissues, but nevertheless, they remain resilient. The pneumohydrostatic pressure within living organisms actively affects their formation, and as a result, the most diverse combinations of shapes appear.

In general construction practice, new design trends have appeared which are related to the use of flexible (soft) structures—structures that in large part emphasize the importance and significance of using the design principles found in the world of living organisms.

By flexible structures, it is meant those structures in which the principal element is a flexible shell (envelope) capable of absorbing only tensile stresses and made mainly from flexible materials; i.e., materials with an airtight or waterproof polymer coating, or from synthetic reinforced membranes. The flexible structures intended for implementing water management measures will be called *flexible hydrotechnical structures.*

The flexible structure is an advanced product of high technology developed in the latter 20th century. Despite the simplicity of design, mass production of flexible structures became possible only after polymer chemistry could be applied to large-scale production of synthetic fibers and resins. It was necessary to establish industrial production of membranes possessing previously incompatible properties:

High abrasive resistance
High tensile strength
Lightness
Durability
Airtightness
Waterproofness
Low cost

Only recently has this task come within the purview of the chemical industry, and now there is the emergence of a new, fully competent type of construction design.

The production of initial materials for flexible shells grew rapidly in the *9th Five-Year Plan:* synthetic resins by a factor of 2, and raw rubber by a factor of 1.7.

Flexible structures are the complete answer to the modern trend in construction toward maximum reduction in structure mass. Structures are the lightest of all those created by man throughout his entire history, and their range of application—especially in the Soviet Union—is extremely broad.

Through the use of flexible structures, it is possible to seek improved shapes of the cross-sectional and longitudinal outlines of concrete dams, drop-inlet spillways, flume channels, earth-lined channels, supporting structures, and water conduits and to create new designs for spillway, training, storage, conveyance and other structures both from traditional as well as flexible materials. The necessity for and expediency of such research were pointed by K.M. Khuberian, V.A. Kiselev, and others in the 1940s.

With the use of flexible structures, it is possible to achieve regulation of water in catchments without using electrical energy, mechanical drives, or complex control systems which ensures operational reliability heretofore unheard of in control structures. When necessary, automation and actuating equipment can be added to the control system.

Materials possessing sufficient chemical stability can be used as flexible conduits and vessels for transporting and storing corrosive substances in the petroleum and chemical industries.

The rapid pace at which these structures can be erected are achieved because of a well thought-out combination of details integrating different functions within a single object. Flexible structures are distinguished chiefly by simplicity of shape.

Application of flexible structures in specialized roles is convenient and effective: vent pipes, casing for reinforced concrete pipes, shells, aprons, and buttresses.

The construction of an irrigation system for which a high efficiency is desired is improbable without the use of components and structural elements made of new materials, e.g., flexible dams and gates, watering hoses and flumes, and connecting, control, and other structures.

The mainly tensile work of flexible structures makes it possible to utilize most fully the strength properties of new effective materials, synthetic fabrics, reinforced and plain membranes, as well as traditional materials (steel cables, wire nets). The great potential for using flexible structures in the different branches of the national economy has been brought about by the multitude of advantages of stressed systems.

Flexible structures are distinguished by lightness and extreme compactness when packaged. They can be transported by any type of conveyance under practically any conditions. For short periods (measured in hours), they can be erected without the aid of auxiliary heavy-duty equipment. The strength of the materials from which flexible structures are made usually depends little on the span size. These structures are earthquakeproof, which is of great significance for their use in seismic regions.

The most important advantages of flexible structures are the moderate cost of synthetic fabrics and films, the possibility of dispensing with the usual construction materials, and the ease of assembly and disassembly which does not require the gathering together of a skilled work force.

One of the primary advantages of flexible structures is the short time in which they can be placed into operation and the possibility of their being utilized at the desired site quickly without constructing expensive aprons or involving other expenditures. This facilitates their rearrangement and remodeling in the future.

Academician V.A. Trapeznikov's economic forecast substantiates the concept reflecting modern rates of development and rapid technical and economic obsolescence of buildings and structures, and emphasizes the expediency of construction within the optimum, most economically profitable period, which is especially typical of flexible structures. As an example, 1 ruble from today's economy will be worth the equivalent of 39 kopeks in 10 years, and 15 kopeks in 20 years. Accordingly, an extended construction time causes a sharp increase in expenses (extending a construction time by 7 years is equivalent to increasing construction costs by a factor of 2).

BASIC DESIGN VARIATIONS

Presently, an acceptable classification of flexible structures has not been defined. It still is not possible to create such a classificaton, since it is difficult to predict the course of future development of flexible structures. Therefore, the indexing of flexible hydrotechnical structures presented on figure 1 should be considered merely an attempt to classifying them, one which will be modified as time passes.

Flexible hydrotechnical structures are divided according to shape and design features into inflatable structures (membrane and composite), and according to operating conditions and designation, into storage, control, connecting, and conveyance structures.

In inflatable structures, the design shape and load carrying capacity are achieved through use of a filler (water, soil, air). In membrane structures, it is achieved by means of buttresses, cables, and wire nets. The composite structures have properties inherent to both the other types.

Analysis of similar structures revealed that they all can be assembled from only four components: cable, rigid sheet, closed, or open shell. The desired flexible structure is obtained depending on which components are used and in the manner they are joined.

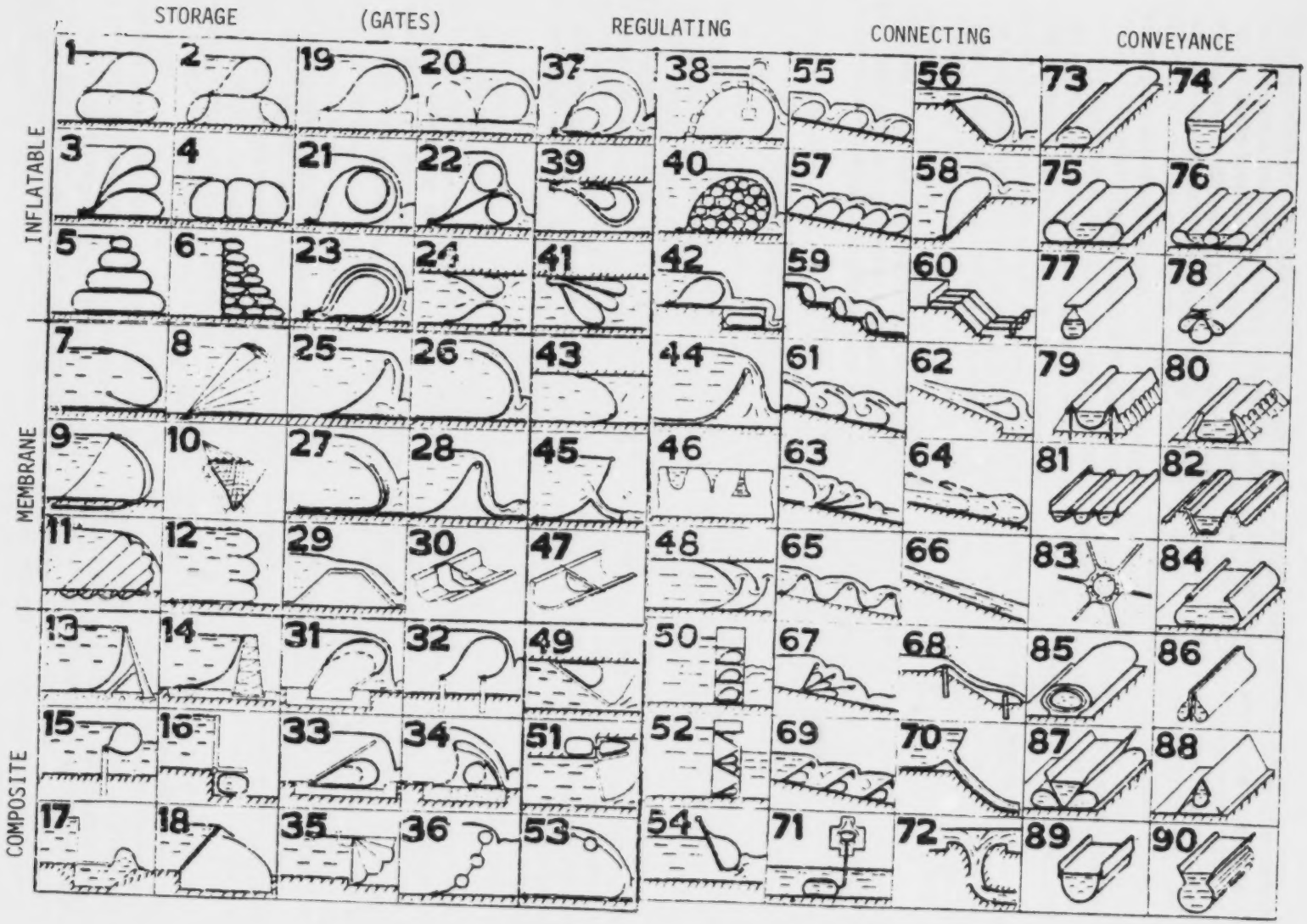

Figure 1. – Diagrams of flexible structures.

Inflatable Structures

Currently, gates with a flexible supporting shell filled with water or air and anchored on a concrete apron are in widespread use (19) (Refer to figure 1.) At times, the concrete apron is replaced by an earthfill shell (1) to which additional shells are added to improve its connection with the channel bed and banks (2).

If the shells are not filled with soil, but rather with sand and gravel or simply with water, then superior structural elements are obtained from which can be constructed: cofferdams (4, 5, and 6) or connections, e.g., fish passages (55); baffle walls (56 and 58); chutes with increased roughness (57); and drops (59 and 60).

To design a two-directional gate, it is necessary to increase the dimensions of the apron and to select a type of joint with the abutments or banks that would not hinder changes in shell position (20).

To improve the operation of the structure, it is made multishelled in the form of either a "baby's rattle" (a free floating shell within a shell, with the outer one attached to the apron—21, 22, and 40) or a "fan" (additional shells are fastened to the point of "restraint" of the main shell—3, 23, and 27).

Flexible inflatable structures (24, 39, and 41) can be beneficial for shutting off the submerged spillways of dams and submerged regulators (tunnel-type gates). When collapsed, they offer practically no resistance to flow; it is not necessary to construct grooves which suffer cavitation damage at high discharges.

The shell[1] can be controlled (inflation and deflation) without complex mechanical equipment and electrical circuits; it is sufficient to fit its upstream face with a "safety belt" (38). This face is buoyant and creates a head which automatically makes the shell fill with water. An opening is provided to discharge the excess on the crest; the shell is emptied through a siphon or pipe.

Using paired shells, it is possible to solve numerous problems with respect to hydraulic automation of water levels in basins, discharges, etc. For instance, on figure 1 (42), both shells are filled with air: as the head on the primary shell rises, the pressure within it increases, and a portion of the air passes into the auxiliary shell. As a result, the crest of the primary shell drops, increasing the area of the overfall. When the head decreases, the air passes from the auxiliary shell to the primary shell. The automatic gate (71), regulating the filling of a basin, operates on the same principle.

Firefighting hoses are used as conveyance structures (73). The hoses are suspended easily (74, 77, and 78), and water, oil, and other liquids can be pumped through them. Arranging hoses in pairs, threes, and more (75 and 76), the discharge capacity of the main increased, through which diverse liquids can be pumped.

Membrane Structures

These bear the pressure from ice or the action of rocks better than rigid arch dams, for instance.

The dam, whose front elevation is shown on figure 1(10), has a saddle shape and is reinforced by a fine mesh net. A permanent earth dam is constructed under the cover of the temporary dam shown on (9).

It is in no way necessary to secure a membrane at a point on is crest; it is sufficient to flip it over a bearer cable and fasten its edges to anchors upstream and downstream (28).

In the structures illustrated on figure 1 [(8) and (11)], cables in the foundation are not fastened to anchors, but rather to a lower membrane buried in the ground. In this manner, it is possible to transfer the load from the water pressure directly to the cables with relatively low stresses within the membrane. The use of a main chord (a bearer cable and stays of different length connecting the cable to the membrane) makes it possible to transfer stresses uniformly from the membrane to shore anchors (26). The dam shown on (7) differs from structure (26) in that its bottom edge is attached to a lower bearer cable rather than to a flexible apron.

As early as the 1940s, the membrane dam design was known under the name of "canvas cofferdam." The flexible panel is fastened to the planned slopes and bed of the stream. Its upper edge is made in the form of a loop, and through it is passed a rod or cable anchored on the banks. When it is

[1]In the context of this report, the term "shell" is used to mean "flexible shell." If the shell is not flexible, it will be so stated.

necessary to pass water through the check dam, one or several flexible sleeves are affixed to it (45) or the appropriate openings are made in it (46).

Temporary, portable, and sectional flumes (30 and 47) are essential items in the rebuilding of irrigation systems. The positive qualities of both reinforced concrete and fiberglass-reinforced plastic flumes are combined in the stationary structures (79, 80, 81, and 84).

Membrane structures can be used to increase the height of a span (12, 27, and 44) and to partition off the submerged openings of regulators (43 and 48). With these, it becomes easy to construct a fall, drop with increased roughness, or fish passage (61, 62, 63, and 65), as well as original transport for delivering fish from headwater to tailwater, and vice versa, in a wedge of water maintained by a membrane that can be shifted along the slope (64).

It is expedient to employ polymer sheeting and fabrics for lining the bottom of irrigation canals (82), protecting earth dams from floodwaters (29 and 66), and for enclosing underground tunnels (83).

Composite Structures

These have the greatest potentials for use. Dams having heads of several tens of meters, mooring and quay walls, and the walls of fish passages and navigation locks can be constructed of flexible materials secured by cable nets, concrete or reinforced concrete buttresses, cutoffs (13), and metal frameworks (14).

An air-filled shell and sheet piling or metal gate with a horizontal axis of rotation can be used to construct an automatic regulator for controlling water levels in reaches (15 and 54). The desired level in a headwater is maintained by structures (16, 17, and 51). For instance, hydraulic gate (17) consists of a [2]-shaped sluice gate, a membrane fastened at one edge to the bottom rim of the sluice gate and on the other to a concrete apron, and conduits connecting the pressure chamber with the headwater and tailwater. The gate is automatically controlled by opening and closing the mouth of the conduit leading to the tailwater.

Performance of a flap (hinged) gate can be improved by replacing its spillway or upstream face with flexible structures (18, 33, 34, and 49). If the rigid faces are left, but they are made mobile, then in conjunction with flexible materials, yet another variation of the gate is obtained (31). Here, the hollow buoyant metal flaps serve as protection when the gate is not operating, and conversely, take part in creating head when the gate is in its designed position. When the flaps are stationary, the gate appears as on figure 1 (32).

Figure 1 (25) shows a hydraulic gate that has no seepage losses when closed. Also of great promise are structures with buoyant chords in the form of air-filled shells (36 and 53).

In fish passages, the gates are flat metal panels with wedge-shaped closures shut off by butterfly valves. However, the gates perform better if the closures are shut off by individual inflatable shells (50) or shells in conjunction with metal panels to protect them from damage and wear (52). The latter can be used as transitions; for this, it is sufficient to group them together (67) or place them at measured distances from each other (69).

A hardened structure is one in which a long air-filled shell is mounted on a flexible casing and then over that are placed reinforcement mesh and a layer of concrete (85).

Flexible materials can be used to create overhanging escapes (68), drops (70), drop-inlet spillways (72), and conveyances (86 through 90).

---

[2]This space was not filled in in the original Russian.

DESIGN OF FLEXIBLE STRUCTURES

OPERATING CONDITIONS AND PREREQUISITES TO DESIGNING FLEXIBLE STRUCTURES

One of the main prerequisites for successful development of a new design trend is applying a theoretical base and reliable calculation and design procedures.

In designing flexible structures, the following must be determined:

- The strength properties of the shell (transverse and longitudinal stresses)
- Geometric characteristics (shape of surface, perimeter, spacing of fastening points)
- Stability of surface shape
- Discharge capacity
- Overall resistance of the structure to shear, etc.

In connection with this, it is necessary to determine the external forces acting on the structure and also to determine the stress-strain state of the flexible shell when in a state of equilibrium while being acted on by external and internal loads.

The external forces acting on the structure usually are divided in the following manner;

1. Depending on the nature of action by the forces on the structure—static and dynamic

2. Depending on their origin—water pressure, deadweight, ground pressure, sediment, seismic waves, etc.

3. Depending on the duration and repetition of the forces on the structure—primary forces

Primary forces include:

- Water pressure (static and dynamic)
- Pressure of sediments desposited upstream from the structure
- Ice pressure if the flexible structure is operating during the winter
- Special loads

It should be noted that flexible structures are classified as prestressed since for flexible structures of the inflatable type and certain composite structures, the load creating the prestressing within the shell is the extra pressure of the water, air, or water and air combined; for flexible structures of the membrane type, it is the difference between the headwater and tailwater levels.

The special feature of flexible shells—the primary element of flexible structures—are their inability to withstand compressive forces which cause a loss of shell shape stability; i.e., the formation of creases on it.

The application of an additional system of forces to a flexible structure causes instantaneous redistribution of the forces and a change in the shape of the shell surface.

A zero-moment stressed state is uniquely possible since they possess no flexing resistance.

So the term *flexible shell* should be used to mean a prestressed thin shell made form materials possessing high tensile strength but incapable of resistance to any other forms of stress (compression, flexure, and shear).

Considerable difficulties are encountered in calculating the static, hydraulic, and seepage properties of flexible structures. The problem of designing flexible shells is nonlinear, in both the *geometric* and *physical* senses. The *physical nonlinearity* results from the fact that the shell material possesses a nonlinear relationship between strains and stresses. The *geometric nonlinearity* results from the fact that, in the transition to a new state of equilibrium, a flexible shell is subjected to finite displacements.

So far, methods of statically modeling the geometrically and physically nonlinear problems have been developed to a sufficient degree solely for gently curved shells. With the exception of research by Dr. Tech. Sci. B.I. Sergeev and his students, and single works by O.G. Zatvornitskii, Iu. P. Borisovets, and N.O. Anvar, no hydraulic and seepage studies have been performed.

Considerable simplifications in static models of flexible hydrotechnical structures can be achieved on the basis of a number of assumptions:

1. Stresses with a shell are applied to its middle surface. The thickness of the materials used to produce flexible structures is 1 to 6 millimeters and so the difference in the deformations of the inner and outer layers is inconsequential.

2. The material of a shell operates in a zone of elastic deformations that conform to Hooke's law. Flexible structures are designed and used with the idea that they are going to be exposed to long-term loads; i.e., a safety factor of 5 to 7 with respect to material strength is applied (on the basis of our experimental results and data presented in [11]). The material of the shell will be functioning in a zone of elastic deformations not exceeding 4 to 6 percent if its prestretching during manufacture is allowed.

3. The stretchability of the material is not considered at first, but then it is introduced in the final step of the calculation.

4. The type of connection between the shell and abutments does not influence the shearing forces.

5. The external hydrodynamic pressure of the liquid from the overflow is replaced by an equivalent hydrostatic pressure.

6. The cross-sectional shape of flexible hydrotechnical structures is not a function of shear stresses.

Given these assumptions, the modeling of cylindrical flexible structures is analogous to the modeling of a flexible ring of unit width loaded with a smoothly variable load. It is assumed that the shell remains cylindrical even after application of the additional system of forces, with only the shape of the generator being changed.

Studies of flexible structures that can be used in the different branches of the national economy have been undertaken and are now being carried out by the following persons: Doctors of Technical Sciences and Professors S.A. Alekseev, A.G. Vorob'ev, G.A. Geniev, A.S. Grigor'ev, A.B. Gubenko, V.V. Ermolov, V.A. Kiselev, V.E. Magula, A.L. Mozhevitinov, P.P. Rozanov, B.I. Sergeev, V.I. Usiukin, V. Feodos'ev, and K.M. Khuberian; Candidates of Technical Sciences A.I. Azovtsev, V.L. Bondarenko, Iu.P. Borisovets, V.A. Volosukhin, B.I. Druz', I.F. Emel'ianov, O.G. Zatvornitskii, Iu. I. Korobanov, S.D. Knoring, A.G. Hazarov, S.M. Pevzner, B.I. Petrakov, M.I. Petrovnin, I.A. Shtokalov, as well as a large group of engineers.

The most comprehensive results in static, hydraulic, and seepage models of flexible hydrotechnical structures have been obtained by Dr. Tech. Sci. B.I. Sergeev [34] as well as his students: I.A. Petrov [27], V.L. Bondarenko [38], A.P. Nazarov, V.A. Volosukhin [39], V.P. Shchedrin [40], Iu. M. Kosichenko [19], and others. O.G. Zatvornitskii's book [12] also is noted; it covers his research as well as that of the Novocherkassk group in part.

STATIC MODELS OF BASIC TYPES OF FLEXIBLE HYDROTECHNICAL STRUCTURES

General Design of Model

In modeling flexible shells, their two states are distinguished: initial (the excess pressure of water, air, or a combination of the two gives the shell a definite shape) and final (an additional system of forces; i.e., design loads, is applied to the shell).

The flexible shells are modeled through the use of procedures and equations from the zero-moment shell theory.

The equilibrium of an element of a shell of arbitrary shape in the final state, assigned in system of coordinates α, β, and Z is examined on figure 2.

The external load shall be considered arbitrary, continuously distributed over the surface of the shell.

Point D is located from point O at an infinitestimal distance dS, which in the Gaussian surface theory is termed the linear element.

The square of the linear element in an orthogonal system of coordinates

$$dS^2 = dS_1^2 + dS_2^2 = A^2\, d\alpha^2 + B^2\, d\beta^2 \qquad (1)$$

Expression (1) is called the first quadratic shape of the surface in the orthogonal system of of coordinates α, β; A and B can be treated as certain

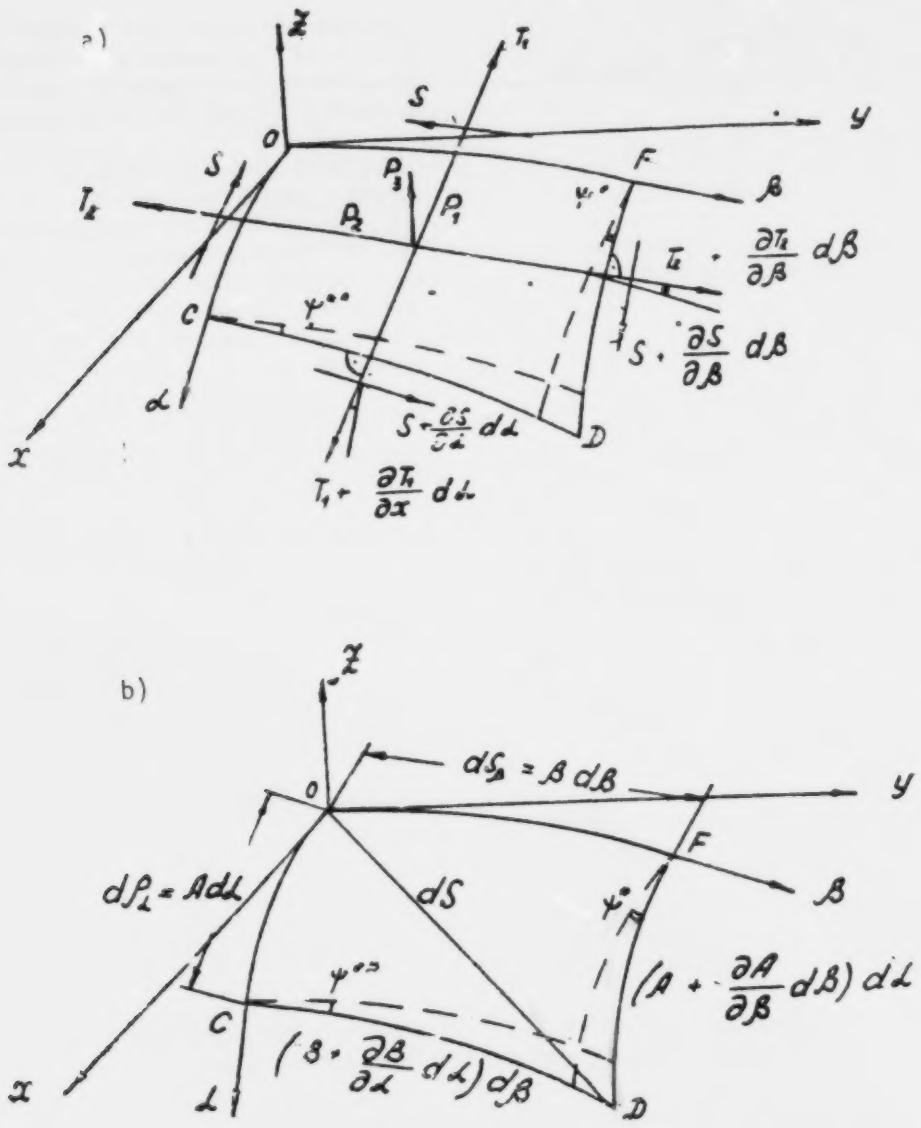

Figure 2. – Interaction of external loads and internal stresses within a flexible shell.

distortion factors that convert the increment of curvilinear coordinates into linear segments.

The total external stress components on the *OX* axis gives:

$$T_1 B d\beta - (T_1 + \frac{\partial T_1}{\partial \alpha} d\alpha)(B + \frac{\partial B}{\partial \alpha} d\alpha) d\beta + SA d\alpha - (S + \frac{\partial S}{\partial \beta} d\beta)(A + \frac{\partial A}{\partial \beta} d\beta) d\alpha + (T_1 + \frac{\partial T_1}{\partial \beta} d\beta)(A + \frac{\partial A}{\partial \beta} d\beta) d\alpha \frac{\partial B}{\partial \alpha} \frac{d\beta}{A} - (S + \frac{\partial S}{\partial \alpha} d\alpha)(B + \frac{\partial B}{\partial \alpha} d\alpha) d\beta \frac{\partial A}{\partial \beta} \frac{d\alpha}{B} + PAB\, d\alpha\, d\beta = 0$$

from which

$$\frac{\partial (T_1 B)}{\partial \alpha} - T_2 \frac{\partial \beta}{\partial \alpha} + \frac{\partial (SA)}{\partial \beta} + \frac{S \partial A}{\partial \beta} - P_1 AB = 0 \qquad (2)$$

or

$$\frac{\partial(T_1 B)}{\partial\alpha} - T_2 \frac{\partial B}{\partial\alpha} + \frac{1}{A}\frac{\partial(SA^2)}{\partial\beta} - P_1 AB = 0$$

where

$$\psi^* \approx \frac{\partial B}{\partial\alpha}\frac{\partial\beta}{A}, \quad \psi^{**} \approx \frac{\partial A}{\partial\beta}\frac{\partial\alpha}{B}$$

Having projected, similarly, the external forces on axis *OY* and *O*, we finally obtain the system:

$$\begin{aligned}
&\frac{\partial(RT_1)}{\partial\alpha} - T_2\frac{\partial B}{\partial\alpha} + \frac{1}{A}\frac{\partial(SA^2)}{\partial\beta} = P_1 AB \\
&\frac{\partial(AT_2)}{\partial\beta} - T_1\frac{\partial A}{\partial\beta} + \frac{1}{B}\frac{\partial(SB^2)}{\partial\alpha} = P_2 AB \\
&\frac{T_1}{R_1} + \frac{T_2}{R_2} = P_3
\end{aligned} \tag{3}$$

For a surface of uniform strength under normal load, these expressions take the form:

$$\begin{aligned}
&\frac{\partial T}{\partial\alpha}\frac{\partial(SB^2)}{\partial\alpha} = \frac{\partial T}{\partial\beta}\frac{\partial(SA^2)}{\partial\beta} \\
&T\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = P
\end{aligned} \tag{4}$$

The statics equations (3), together with the nonlinear physical equations (deformation laws of Mooney, Treloart, Mooney-Rivlin, Rivlin, Biderman's logarithmic, Neo-Hooke's, Hart-Smith), the nonlinear geometric equations (1), the boundary conditions and the Codazzi-Gauss conditions [22] comprise the complete set of equations whose solution is far from always being possible. Only certain parts of the problem have been investigated so far in the Soviet and foreign literature.

Below is examined the class of cylindrical shells to which flexible hydrotechnical structures are related and for which the solutions are considerably simpler. The calculation procedure and general design functions of the main types of flexible hydrotechnical structures have been set forth by Dr. Tech. Sci. B.I. Sergeev and Can. Tech. Sci. R.A. Volosukhin.

For cylindrical shells, it is more convenient to use the cylindrical system of coordinates, Z, θ. Here, $A = P_1$, $B = 1$, $P_1 = P$, $P = {}^{3}$.

Equations (3) take the following form:

$$\begin{aligned}
&\frac{\partial T_1}{\partial\theta} + R\frac{\partial S}{\partial Z} = P_1 R \\
&R\frac{\partial T_2}{\partial Z} + \frac{\partial S}{\partial\theta} = P_2 R \\
&T_1 = P_3 R
\end{aligned} \tag{5}$$

In the case of normal load alone:

$$S = -\int \frac{\partial P_3}{\partial\theta}\,dZ + C_1(\theta)$$

$$T_2 = -\frac{1}{R}\int \frac{\partial S}{\partial\theta}\,dZ + C_2(\theta)$$

Analogous equations can be obtained from examination of the equilibrium of an absolutely flexible ring of unit width, which are distinguished by physical image.

From the sum of the *OC* components, obtain (fig. 3):

$$-T_o Cos(\pi - \varphi_o) + T Cos(\pi - \varphi) + \int_{\varphi_o}^{\varphi} P(-dy) = 0$$

and from this, given $P = 2ay + b$

$$-T_o Cos\,\varphi_o + T Cos\,\varphi + a(y^2 - y_o^2) + b(y - y_o) = 0 \tag{6}$$

From the total component of external forces on an infinitesimal element (fig. 5)

$$R\,dT + g_o R\,Sin\,\varphi\,d\ell = 0 \tag{7}$$

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[3]Left blank in the original Russian.

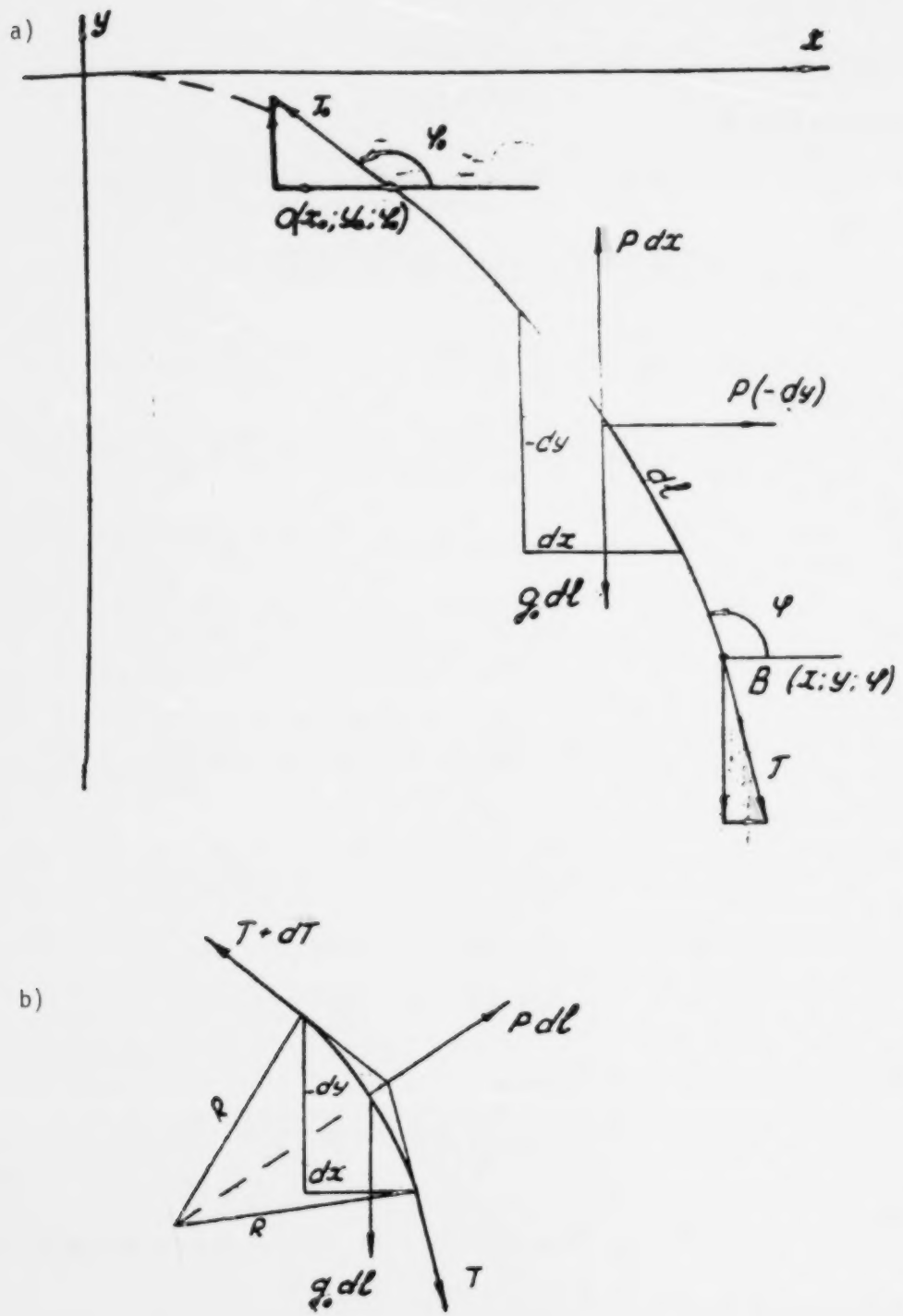

Figure 3. – Diagram of forces acting on an element of a flexible shell.

or

$$dT = g_o\, dy$$

Integrating (7)

$$T = T_o + g_o\,(y - y_o) \tag{8}$$

Substituting (8) in (6)

$$ay^2 + (b + g_o \operatorname{Cos} \varphi)\, y + T_o\,(\operatorname{Cos} \varphi - \operatorname{Cos} \varphi_o) - y_o\,(b + ay_o + g_o \operatorname{Cos} \varphi) = 0$$

from which

$$y = -\frac{(v + g_o \operatorname{Cos} \varphi) + \varepsilon_1 \sqrt{A_o \operatorname{Cos}^2 \varphi + A_1 \operatorname{Cos} \varphi + A_2}}{2a} \tag{9}$$

where

$$A_o = g_o^2; \quad A_1 = 2\,(bg_o - 2aT_o + 2ay_o g_o)$$
$$A_2 = b^2 + 4a\,[T_o \operatorname{Cos} \varphi_o + y_o\,(b + ay_o)]$$

Differentiating (9)

$$\frac{dy}{\partial \varphi} = \frac{g_o}{2a} \operatorname{Sin} \varphi - \frac{\varepsilon_2\,(2A_o \operatorname{Cos} \varphi + A_1) \operatorname{Sin} \varphi}{4a \sqrt{A_o \operatorname{Cos}^2 \varphi + A_1 \operatorname{Cos} \varphi + A_2}}$$

Since

$$\frac{dy}{dx} = \varepsilon_1, \quad \operatorname{Tan} \varphi, \quad \text{where Sgn } \varepsilon_1 = \begin{cases} -1, \text{ if } y'y'' < 0 \\ +1, \text{ if } y'y'' > 0 \end{cases}$$

then

$$\frac{dx}{d\varphi} = \frac{g_o}{2a\varepsilon_1} \operatorname{Cos} \varphi - \frac{\varepsilon_2}{4a\varepsilon_1} \frac{2A_o \operatorname{Cos}^2 \varphi + A \operatorname{Cos} \varphi}{\sqrt{A_o \operatorname{Cos}^2 \varphi + A \operatorname{Cos} \psi + A_2}}$$

from which

$$x = x_o + \frac{g_o}{2a\varepsilon_1} (\operatorname{Sin} \varphi - \operatorname{Sin} \varphi_o) - \frac{\varepsilon_2}{4a\varepsilon_1} \int_{\varphi_o}^{\varphi} \frac{2A_o \operatorname{Cos}^2 \varphi + A_1 \operatorname{Cos} \varphi}{\sqrt{A_o \operatorname{Cos}^2 \varphi + A_1 \operatorname{Cos} \varphi + A_2}}\, d\varphi \tag{10}$$

Similarly, obtain the expression for ℓ

$$(\ell = \ell_o) - \frac{g_o}{2a\varepsilon} (\varphi - \varphi_o) + \frac{\varepsilon_2}{4a\varepsilon_1} \int_{\varphi_o}^{\varphi} \frac{(2A_o \operatorname{Cos} \varphi + A)\, d\varphi}{\sqrt{A_o \operatorname{Cos}^2 \varphi + A_1 \operatorname{Cos} \varphi + A_2}} \tag{11}$$

Obtain the following expression for determining the cross-sectional area:

$$S = S_o + \int_{y_o}^{y} x\, dy = S_o + xy - x_o y_o - \int_{y_o}^{y} y\, dx$$

Since from the sum of the *OY* components

$$T_o \operatorname{Sin} \varphi_o - T \operatorname{Sin} \varphi + \varepsilon_1 \int_{x_o}^{x} (2ay + b)\, dx - g_o\,(\ell - \ell_o) = 0$$

then

$$-\int_{x_o}^{x} y\, dx = \frac{1}{2a\varepsilon_1} [T_o\,(\operatorname{Sin} \varphi_o - \operatorname{Sin} \varphi) - g_o\,(\operatorname{Sin} \varphi - y_o \operatorname{Sin} \varphi) + b\varepsilon_1\,(x - x_o) - g_o\,(\ell - \ell_o)]$$

consequently

$$\delta\,(S, S_o) = \delta\,(xy, x_o y_o) - \frac{T_o}{2a\varepsilon_1}\, \delta \operatorname{Sin}\,(\varphi, \varphi_o) + \frac{b}{2a}\, \delta\,(x, x_o) - \frac{g_o}{2a\varepsilon} [\delta\,(\ell, \ell_o) + \delta\,(y, y_o) \operatorname{Sin} \varphi]$$

where δ denotes the increment of the function standing behind it.

Thus,

$$\delta(S, S_o) = S - S_o, \quad \delta(xy, x_o y_o) = xy - x_o y_o; \text{ etc.}$$

At

$$g_o^2 \operatorname{Cos}^2 \varphi \approx 0$$

which is possible for single-layer flexible hydrotechnical structures, since this quantity has a value on the order of 9×10^{-6} and introduces up to 2 to 3 percent error into the calculation, a set of equations in the following form is obtained

$$y = -\frac{(b + g_o \operatorname{Cos} \varphi) + \varepsilon_2 \sqrt{A_1 \operatorname{Cos} \varphi + A_2}}{2}$$

$$\delta(x, x_o) = \frac{g_o}{2a\varepsilon_1} \delta \operatorname{Sin}(\varphi, \varphi_o) - \frac{\varepsilon_2}{\varepsilon_1} \frac{A_1}{4a} \int_{\varphi_o}^{\varphi} \frac{\operatorname{Cos} \varphi \, d\varphi}{\sqrt{A_1 \operatorname{Cos} \varphi + A_2}}$$

$$\delta(\ell, \ell_o) = -\frac{g_o}{2a\varepsilon_1} \delta(\varphi, \varphi_o) - \frac{\varepsilon_2}{\varepsilon_1} \frac{A_1}{4a} \int_{\varphi_o}^{\varphi} \frac{d\varphi}{\sqrt{A_1 \operatorname{Cos} \varphi + A_2}} \tag{12}$$

$$\delta(S, S_o) = \delta(xy, x_o y_o) + \frac{b}{2a} \delta(x, x_o) - \frac{T_o}{2a\varepsilon_1} \delta \operatorname{Sin}(\varphi, \varphi_o) - \frac{g_o}{2a\varepsilon_1} [\delta(\ell, \ell_o) + \delta(y, y_o) \operatorname{Sin} \varphi]$$

where

$$A_1 = 2(bg_o - 2aT_o), \quad A_2 = b + 4a[T_o \operatorname{Cos} \varphi_o + y_o(b + ay_o)]$$

For $a \to 0$ and $g_o \neq 0$, continuing to the limit, obtain:

$$\lim_{a \to 0} y = \lim_{a \to 0} \frac{(b + g_o \operatorname{cos} \varphi) + \varepsilon_2 \sqrt{(b + g_o \operatorname{Cos} \varphi)^2 - 4C\, T_o (\operatorname{Cos} \varphi - \operatorname{Cos} \varphi_o) - y_o (b + ay_o + g_o \operatorname{Cos} \varphi)}}{2a}$$

$$= \lim_{a \to 0} \frac{T_o (\operatorname{Cos} \varphi_o - \operatorname{Cos} \varphi) + y_o (b + g_o \operatorname{Cos} \varphi)}{b + g_o \operatorname{Cos} \varphi}$$

from which

$$\delta(y, y_o) = \frac{T_o (\operatorname{Cos} \varphi_o - \operatorname{Cos} \varphi)}{b + g_o \operatorname{Cos} \varphi} \tag{13}$$

Having differentiated (13)

$$dy = \frac{T_o \operatorname{Sin} \varphi (b + g_o \operatorname{Cos} \varphi) + T_o g_o \operatorname{Sin} \varphi (\operatorname{Cos} \varphi_o - \operatorname{Cos} \varphi) \, d\varphi}{(b + g_o \operatorname{Cos} \varphi)^2}$$

then

$$dx = \frac{dy}{\varepsilon_1 \operatorname{Tan} \varphi} = \frac{T_o \operatorname{Cos} \varphi (b + g_o \operatorname{Cos} \varphi) + T_o \cdot g_o \operatorname{Cos} \varphi (\operatorname{Cos} \varphi_o - \operatorname{Cos} \varphi)}{\varepsilon_1 (b + g_o \operatorname{Cos} \varphi)^2} d\varphi$$

$$= \frac{T_o (b + g_o \operatorname{Cos} \varphi_o) \operatorname{Cos} \varphi}{\varepsilon_1 (b + g_o \operatorname{Cos} \varphi)^2} d\varphi \tag{14}$$

or

$$\delta(x, x_o) = \frac{T_o (b + g_o \operatorname{Cos} \varphi_o)}{\varepsilon_1} \int_{\varphi_o}^{\varphi} \frac{\operatorname{Cos} \varphi \, d\varphi}{(b + g_o \operatorname{Cos} \varphi)^2}$$

Similarly, obtain the expression for ℓ

$$d\ell = -\frac{ay}{\varepsilon_1 \operatorname{Sin}\varphi} = -\frac{T_o (b + g_o \operatorname{Cos}\varphi_o)}{\varepsilon_1 (b + g_o \operatorname{Cos}\varphi)^2} d\varphi$$

$$\delta(\ell, \ell_o) = -\frac{T_o (b + g_o \operatorname{Cos}\varphi_o)}{\varepsilon_1} \int_{\varphi_o}^{\varphi} \frac{d\varphi}{(b + g_o \operatorname{Cos}\varphi)^2} \tag{15}$$

for

$$a \neq 0, \qquad g_o \to 0$$

$$y = \frac{-(b + g_o \operatorname{Cos}\varphi) + \varepsilon_2 \sqrt{A_1 \operatorname{Cos}\varphi + A_2}}{2a}$$

$$\delta(x, x_o) = -\frac{\varepsilon_2}{\varepsilon_1} \frac{A}{4C} \int_{\varphi_o}^{\varphi} \frac{\operatorname{Cos}\varphi \, d\varphi}{\sqrt{A_1 \operatorname{Cos}\varphi + A_2}} \tag{16}$$

$$\delta(\ell, \ell_o) = -\frac{\varepsilon_2}{\varepsilon_1} \frac{A_1}{4a} \int_{\varphi_o}^{\varphi} \frac{d\varphi}{\sqrt{A_1 \operatorname{Cos}\varphi + A_2}}$$

$$\delta(s, s_o) = \delta(xy, x_o y_o) + \frac{b}{2a} \delta(x, x_o) \frac{T_o}{2a} \delta \operatorname{Sin}(\varphi, \varphi_o)$$

where

$$A_1 = -4at_o, \qquad A_2 = b^2 + 4a[T_o \operatorname{Cos}\varphi_o + y_o (b + ay_o)]$$

for

$$a \to 0, \qquad g_o \to 0$$

$$\delta(y, y_o) = \frac{T_o (\operatorname{Cos}\varphi_o - \operatorname{Cos}\varphi)}{b}$$

$$\delta(x, x_o) = \frac{T_o}{\varepsilon_1 b} \delta \operatorname{Sin}(\varphi, \varphi_o) \tag{17}$$

$$\delta(\ell, \ell_o) = -\frac{T_o}{\varepsilon_1 b} \delta(\varphi, \varphi_o)$$

$$\delta(s, s_o) = \frac{1}{b}\left\{\frac{1}{\varepsilon_1 b}(\operatorname{Sin}\varphi_o - x_o)(\operatorname{Cos}\varphi - \operatorname{Cos}\varphi_o) + \frac{1}{2\varepsilon_1 b}\left[(\varphi - \varphi_o) - \frac{\delta \operatorname{Sin}(2\varphi, 2\varphi_o)}{2}\right]\right\}$$

The integrals

$$\tau_1 = \int_{\varphi_o}^{\varphi} \frac{\operatorname{Cos}\varphi \, d\varphi}{\sqrt{A_1 \operatorname{Cos}\varphi + A_2}}; \qquad \tau_2 = \int_{\varphi_o}^{\varphi} \frac{d\varphi}{\sqrt{A_1 \operatorname{Cos}\varphi + A_2}}$$

are related to the class of ellipticals. Now examine their reduction to the normal Legendre form. Three cases are possible here: (1) $A_1 > 0$, (2) $A_1 < 0$, and (3) $A_1 = 0$.

Consider only the first two cases, because for $A_1 = 0$ the above integrals are expressed through elementary functions, which are not significant.

Given, (1): $A_1 > 0$, $\varphi = 2\,\text{ш}$

then

$$d\varphi = 2\, d\psi$$

Since

$$\text{Cos } 2\,\psi = 1 - 2\,\text{Sin}^2\,\psi$$

then

$$\tau_1 = \int_{\varphi_o}^{\varphi} \frac{\text{Cos}\,\varphi\, d\,\varphi}{\sqrt{A_1\,\text{Cos}\,\varphi + A_2}} = 2\int_{\psi_o}^{\psi} \frac{(1 - 2\,\text{Sin}^2\,\psi)\, d\psi}{\sqrt{A_1 + A_2 - 2A_1\,\text{Sin}^2\,\psi}}$$

$$= \frac{2}{\sqrt{A_1 + A_2}} \int_{\psi_o}^{\psi} \frac{(1 - 2\,\text{Sin}^2\,\psi)\, d\psi}{\sqrt{1 - \frac{2A}{A_1 + A_2}\,\text{Sin}\,\psi}} = \frac{2K}{\sqrt{2A_1}} \int_{\psi_o}^{\psi} \frac{(1 - 2\,\text{Sin}^2\,\psi)\, d\psi}{\sqrt{1 - K^2\,\text{Sin}^2\,\psi}}$$

$$= \frac{K\sqrt{2A}}{A_1} \left\{ \int_{\psi_o}^{\psi} \frac{d\,\psi}{\sqrt{1 - K^2\,\text{Sin}^2\,\psi}} + \frac{2}{K^2} \left[\int_{\psi_o}^{\psi} \sqrt{1 - K^2\,\text{Sin}^2\,\psi}\, d\psi - \int_{\psi_o}^{\psi} \frac{d\psi}{\sqrt{1 - K^2\,\text{Sin}^2\,\psi}} \right] \right\}$$

$$= \frac{K\sqrt{2A}}{A} \left[\frac{2}{K^2}\, \delta E\,(K;\, \psi,\, \psi_o) - \left(\frac{2}{K^2} - 1 \right) \delta F\,(K;\, \psi,\, \psi_o) \right]$$

$$= \frac{K\sqrt{2A_1}}{A_1}\, \delta A\,(K;\, \psi,\, \psi_o)$$

where

$K^2 = \dfrac{2A_1}{A_1 + A_2}$ is the modulus of the elliptic integrals

$F\,(K,\, \psi) = \displaystyle\int_{\psi_o}^{\psi} \frac{d\psi}{\sqrt{1 - K^2\,\text{Sin}^2\,\psi}}$ is an elliptic integral of the first kind

$E\,(K,\, \psi) = \displaystyle\int_{\psi_o}^{\psi} \sqrt{1 - K^2\,\text{Sin}^2\,\psi}\; d\psi$ is an elliptic integral of the second kind

$$\delta F\,(K;\, \psi,\, \psi_o) = F\,(K,\, \psi) - F\,(K,\, \psi_o)$$
$$\delta E\,(K;\, \psi,\, \psi_o) = E\,(K,\, \psi) - E\,(K,\, \psi_o)$$
$$\delta A\,(K;\, \psi,\, \psi_o) = \frac{2}{K^2}\, \delta E\,(K;\, \psi,\, \psi_o) - \left(\frac{2}{K^2} - 1 \right) \delta F\,(K;\, \psi,\, \psi_o)$$

Analogous transformations are performed for the second integral.

$$\tau^2 = \int_{\varphi_o}^{\varphi} \frac{d\varphi}{\sqrt{A_1\,\text{Cos}\,\varphi + A_2}} = 2\int_{\psi_o}^{\psi} \frac{d\psi}{\sqrt{A_1 + A_2 - 2A_1\,\text{Sin}^2\,\psi}}$$

$$= \frac{K\sqrt{2A_1}}{A_1} \int_{\psi_o}^{\psi} \frac{d\psi}{\sqrt{1 - K^2\,\text{Sin}^2\,\psi}} = \frac{K\sqrt{2A_1}}{A_1}\, \delta F\,(K;\, \psi,\, \psi_o)$$

For $K > 1$ and using the substitutions

$$\bar{K} = \frac{1}{K};\ \bar{\psi} = \text{arc Sin}\,(K \cdot \sin\,\psi),\ F\,(K,\, \psi) = \bar{K} \cdot F\,(\bar{K},\, \bar{\psi})$$

$$E\,(K,\, \psi) = \frac{1}{R}\, E\,(\bar{K},\, \bar{\psi}) + \left(\bar{K} - \frac{1}{R} \right) F\,(\bar{K},\, \bar{\psi})$$

then

$$\tau_1 = \frac{K\sqrt{2A_1}}{A_1}\, \delta A\,(K;\, \psi,\, \psi_o) = \frac{\sqrt{2A_1}}{A_1} \left[2\delta E\,(\bar{K};\, \bar{\psi},\, \psi_o) - F\,(\bar{K},\, \bar{\psi},\, \bar{\psi}_o) \right]$$

$$\tau_2 = \frac{K\sqrt{2A_1}}{A_1}\, \delta F\,(K;\, \psi,\, \psi_o) = \frac{\sqrt{2A}}{A}\, F\,(\bar{K};\, \bar{\psi},\, \bar{\psi}_o)$$

Given, (2): $A < 0$, $\varphi = \pi - 2\psi$

from which

$$d\varphi = -2\,d\psi$$

Consequently

$$\tau_1 = \int_{\varphi_0}^{\varphi} \frac{d\varphi}{\sqrt{A_1 \operatorname{Cos}\varphi + A_2}} = 2\int_{\varphi_0}^{\varphi} \frac{d\psi}{\sqrt{|A_1| + A_2 - 2|A_1| \operatorname{Sin}^2\psi}}$$

$$= -\frac{K\sqrt{2|A_1|}}{|A_1|}\int_{\varphi_0}^{\varphi} \frac{(1 - 2\operatorname{Sin}^2\psi)\,d\psi}{\sqrt{1 - K^2\operatorname{Sin}^2\psi}}$$

$$= -\frac{K\sqrt{2|A_1|}}{|A_1|}\left[\frac{2}{K^2}\delta E(K; \psi, \psi_0) - \left(\frac{2}{K^2} - 1\right)\delta F(K; \psi, \psi_0)\right]$$

$$= -\frac{K\sqrt{2|A_1|}}{|A_1|}\delta A(K; \psi, \psi_0)$$

and

$$\tau_2 = \int_{\varphi_0}^{\varphi} \frac{d\varphi}{\sqrt{A_1 \operatorname{Cos}\varphi + A_2}} = -2\int_{\varphi_0}^{\varphi} \frac{d\psi}{\sqrt{|A_1| + A_2 - 2|A_1| \operatorname{Sin}^2\psi}}$$

$$= -\frac{K\sqrt{2|A_1|}}{|A_1|}\int_{\varphi_0}^{\varphi} \frac{d\psi}{\sqrt{1 - K^2\operatorname{Sin}^2\psi}} = -\frac{K\sqrt{2|A_1|}}{|A_1|}\delta F(K; \psi, \psi_0)$$

For $K > 1$, analogously to the first case

$$\tau_1 = \frac{-K\sqrt{2|A_1|}}{|A_1|}\delta A(K; \psi, \psi_0) = -\frac{\sqrt{2|A_1|}}{|A_1|}\,2\,\delta E(\bar{K}; \bar{\psi}, \bar{\psi}_0) - F(\bar{K}, \bar{\psi}, \bar{\psi}_0)$$

$$\tau_2 = -\frac{K\sqrt{2|A_1|}}{|A_1|}\delta F(K; \psi, \psi_0) = -\frac{\sqrt{2|A_1|}}{|A_1|}F(\bar{K}; \bar{\psi}, \bar{\psi}_0)$$

Determination of stresses developing within a weighable flexible hydrotechnical structure. – Now examine the equilibrium of that portion of the shell located to the right of section I-I on figure 4. From the sum of the OX components:

a) For a flexible inflatable structure (fig. 4a)

$$T_0 \operatorname{Cos}\varphi_0 - (T_0 - g_0 H)\operatorname{Cos}\varphi_5 + E_1 + E_2 - E_3 - E_4 = 0$$

from which

$$T_0 = \frac{E_1 + E_2 - E_3 - E_4}{\operatorname{Cos}\varphi_5 - \operatorname{Cos}\varphi_0} + g_0 H \operatorname{Cos}\varphi_5$$

where

$$E_1 = F_0 H,\ E_2 = \frac{\gamma_1 (H - h_1)^2}{2},\quad E_3 = \frac{\gamma_2 Z_0 h_{3y}}{2},\quad E_4 = \frac{\gamma_3 (H - h_{3y})}{2}$$

consequently

$$T_0 = \frac{2P_0 H + \gamma_1 (H - h_1)^2 - \gamma_2 Z_0 h_{3y} - \gamma_3 (H - h_{3y})^2 gH \operatorname{Cos}\varphi_5}{2(\operatorname{Cos}\varphi_5 - \operatorname{Cos}\varphi_0)}$$

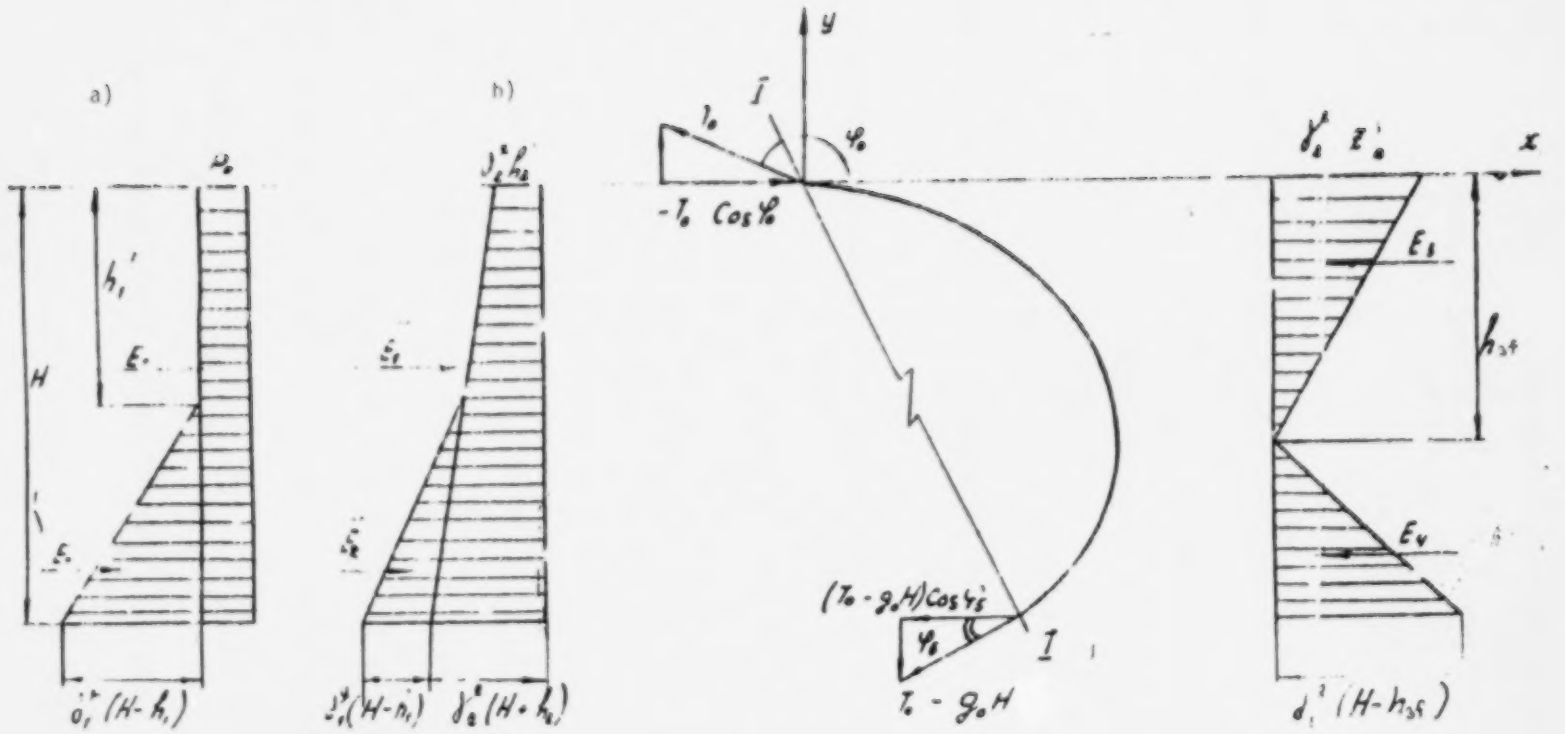

Figure 4. – Design diagram for determining transverse stress.

b) For a flexible membrane structure (fig. 4b)

$$T_o = \frac{\bar{E}_1 + \bar{E}_2 - \bar{E}_3 - E_4}{\text{Cos } \varphi_5 - \text{Cos } \varphi_o} + g_o H \text{ Cos } \varphi_5$$

where

$$\bar{E}_1 = \frac{\gamma_2 (H^2 + h_2) H}{2}, \qquad E_2 = \frac{\gamma_1 (H - h_1)^2}{2}$$

then

$$T_o = \frac{\gamma_1 (H - h_1)^2 + \gamma_2 (H_1 + h_2) H - \gamma_2 Z_o h_{3\gamma} - \gamma_3 (H - h_{3\gamma})^2}{2 \text{ Cos } \varphi_5 \cdot \text{ Cos } \varphi_o)} + g_o H \text{ Cos } \varphi_5$$

Determination of Boundary Angles

The equation for determining the boundary angles on the design segments from equation (6) is obtained

$$\varphi = \text{arc Cos} \left[\frac{T_o \text{ Cos } \varphi_o - a (y^2 - y_o^2) b (y - y_o)}{T_o + g_o (y - y_o)} \right]$$

General Design Equations for Main Types of Flexible Hydrotechnical Structures

1. $A \neq 0, \qquad g_o \neq 0$

Due to the limited amount of work that has been done, the design equations for this case are presented only in integral form:

$$y = \frac{-(b + g_o \text{ Cos } \varphi) + \varepsilon_2 \sqrt{A_o \text{ Cos}^2 \varphi + A_1 \text{ Cos } \varphi + A_2}}{2a}$$

$$\delta (x, x_o) = \frac{g_o}{2a\varepsilon_1} \delta \text{ Sin } (\varphi, \varphi_o) - \frac{\varepsilon_2}{\varepsilon_1} \frac{1}{4a} \int_{\varphi_o}^{\varphi} (2A_o \text{ Cos}^2 \varphi + A_1 \text{ Cos } \varphi) \, d\varphi$$

$$\delta (\ell, \ell_o) = -\frac{g_o}{2a\varepsilon_1} \delta (\varphi, \varphi_o) + \frac{\varepsilon_2}{\varepsilon_1} \frac{}{4a} \int_{\varphi_o}^{\varphi} \frac{(2A_o \text{ Cos } \varphi + A_1) \, d\varphi}{\sqrt{A_o \text{ Cos}^2 \varphi + A_1 \text{ Cos } \varphi + A_2}} \qquad (18)$$

$$\delta (s, s_o) = \delta (xy, x_o y_o) + \frac{b}{2a} - \frac{T_o}{2a} \delta \text{ Sin } (\varphi, \varphi) - \frac{g_o}{2a} [\delta (\ell, \ell_o) + \delta (y, y_o) \text{ Sin } \varphi]$$

where

$$A_o = g_o^2, \qquad A_1 = 2 [bg_o - 2a (T_o + g_o y_o)]$$

$$A_2 = b^2 + 4a [T_o \text{ Cos } \varphi_o + y_o (b + ay_o)]$$

$$\delta (x, x_o) = x - x_o, \qquad \delta (y, y_o) = y - y_o$$

$$\delta (\ell, \ell_o) = \ell - \ell_o, \qquad \delta (s, s_o) = s - s_o$$

$$\delta \text{ Sin } (\varphi, \varphi_o) = \text{Sin } \varphi - \text{Sin } \varphi_o, \qquad \delta (xy, x_o y_o) = xy - x_o y_o$$

$$\text{Sgn } \varepsilon_2 = \begin{cases} -1, \text{ if } y'y'' < 0 \\ +1, \text{ if } y'y'' > 0 \end{cases}$$

$$\text{Sgn } \varepsilon_2 = \begin{cases} \text{if } a > 0, & b > 0, & p < 0, & a < 0, & p \gtrless 0 \\ -1, \text{ if } a < 0, & b < 0, & p > 0, & & \\ \text{if } a > 0, & b > 0, & p < 0, & & \\ +1, \text{ if } a > 0, & b < 0, & p < 0, & a < 0, & p \gtrless 0 \end{cases}$$

2. $g_o^2 \text{ Cos}^2 \varphi = 0$ $\qquad \underline{K < 1}$

$$y = \frac{-(b + g_o \text{ Cos } \varphi) + \varepsilon_2 \sqrt{A \text{ Cos } \varphi + A_2}}{2a}$$

$$\delta (x, x_o) = \frac{g_o}{2a\varepsilon_1} \delta \text{ Sin } (\varphi, \varphi_o) \mp \frac{\varepsilon_2}{\varepsilon_1} \frac{K \sqrt{2 |A_1|}}{4a} \delta A (K; \psi, \psi_o)$$

$$\delta (\ell, \ell_o) = -\frac{g_o}{2a\varepsilon_1} \delta (\varphi, \varphi_o) \pm \frac{\varepsilon_2}{\varepsilon_1} \frac{K \sqrt{2 |A_1|}}{4a} \delta F (K; \psi, \psi_o) \qquad (19)$$

$$\delta (s, s_o) = \delta (xy, x_o y_o) + \frac{b}{2a} \delta (x, x_o) - \frac{T_o}{2a\varepsilon_1} \delta \text{ Sin } (\varphi, \varphi_o) - \frac{g_o}{2a\varepsilon_1} [\delta (\ell, \ell_o) + \delta (y, y_o) \text{ Sin } \varphi]$$

where

$$A_1 = 2 (bg_o = 2aT_o), \quad A_2 = b^2 + 4a [T_o \text{ Cos } \varphi_o + y_o (b + ay_o)], \quad K^2 = \frac{2 |A_1|}{|A_1| + A_2}$$

$$\delta F (K; \psi, \psi_o) = F (K, \psi) - F (K, \psi_o)$$

$$\delta E (K; \psi, \psi_o) = E (K, \psi) - E (K, \psi_o)$$

$$\delta A (K; \psi, \psi_o) = \frac{2}{K^2} \delta E (K; \psi, \psi_o) - \left(\frac{2}{K^2} - 1 \right) \delta F (K; \psi, \psi_o)$$

$\underline{K > 1}$

$$y = \frac{(b + g_o \text{ Cos } \varphi) + \varepsilon_2 \sqrt{A_1 \text{ Cos } \varphi + A_2}}{2a}$$

$$\delta (x, x) = \frac{g_o}{2a\varepsilon_1} \delta \text{ Sin } (\varphi, \varphi_o) \mp \frac{\varepsilon_2}{\varepsilon_1} \frac{\sqrt{2 |A_1|}}{4a} [2\delta E (\bar{K}; \bar{\psi}, \bar{\psi}_o) - \delta F (\bar{K}; \bar{\psi}, \bar{\psi})]$$

$$\delta (\ell, \ell_o) = -\frac{g_o}{2a\varepsilon_1} \delta (\varphi, \varphi_o) \pm \frac{\varepsilon_2}{\varepsilon_1} \frac{\sqrt{2 |A_1|}}{4a} \delta F (\bar{K}; \bar{\psi}, \bar{\psi}_o) \qquad (20)$$

$$\delta (s, s_o) = \delta (xy, x_o y_o) + \frac{b}{2a} \delta (x, x_o) - \frac{T_o}{2a\varepsilon_1} \delta \text{ Sin } (\varphi, \varphi_o) - \frac{g_o}{2a\varepsilon_1} [\delta (\ell, \ell_o) + \delta (y, y_o) \text{ Sin } \varphi]$$

where

$$\bar{K} = 1/K, \qquad \bar{\psi} = \text{arc Sin } (K \cdot \text{Sin } \psi)$$

3. $a \to 0, \qquad g_o \neq 0$

$$\delta (y, y_o) = \frac{T_o \delta \text{ Cos } (\varphi_o, \varphi)}{b + g_o \text{ Cos } \varphi}$$

$$\delta(x, x_o) = \frac{T_o(b + g_o \operatorname{Cos}\varphi_o)}{b^2 - g_o^2}\left\{\left[\frac{b \operatorname{Sin}\varphi}{b + g_o \operatorname{Cos}\varphi} - \frac{2g_o}{\sqrt{b^2 + g^2}} \operatorname{arc\,Tan}\frac{(b - g_o)\operatorname{Tan}\frac{\varphi}{2}}{\sqrt{b^2 - g_o^2}}\right]\right.$$

$$\left. - \left[\frac{b \operatorname{Sin}\varphi_o}{b + g_o \operatorname{Cos}\varphi} - \frac{2g_o}{\sqrt{b^2 - g_o^2}} \operatorname{arc\,Tan}\frac{(b - g_o)\operatorname{Tan}\frac{\varphi}{2}}{\sqrt{b^2 + g_o^2}}\right]\right\} \qquad (21)$$

$$\delta(\ell, \ell_o) = \frac{T_o(b + g_o \operatorname{Cos}\varphi_o)}{g_o^2 - b^2}\left\{\left[\frac{g_o \operatorname{Sin}\varphi}{b + g_o \operatorname{Cos}\varphi} - \frac{2b}{\sqrt{b^2 - g_o^2}} \operatorname{arc\,Tan}\frac{(b - g_o)\operatorname{Tan}\frac{\varphi}{2}}{\sqrt{b^2 - g^2}}\right]\right.$$

$$\left. - \left[\frac{g_o \operatorname{Sin}\varphi_o}{b + g_o \operatorname{Cos}\varphi_o} - \frac{2b}{\sqrt{b^2 - g_o^2}} \operatorname{arc\,Tan}\frac{(b - g_o)\operatorname{Tan}\frac{\varphi}{2}}{\sqrt{b^2 - g_o^2}}\right]\right\}$$

4. $a \neq 0, \quad g_o \to 0$

$$\underline{K < 1}$$

$$y = \frac{-b + \varepsilon_2\sqrt{A_1 \operatorname{Cos}\varphi + A_2}}{2a}$$

$$\delta(x, x_o) = \mp\frac{\varepsilon_2}{\varepsilon_1}\frac{K\sqrt{2|A_1|}}{4a}\delta h(K; \psi, \psi_o)$$

$$\delta(\ell, \ell_o) = \pm\frac{\varepsilon_2}{\varepsilon_1}\frac{K\sqrt{2|A_1|}}{4a}\delta F(K; \psi, \psi_o) \qquad (22)$$

$$\delta(s, s_o) = \delta(xy, x_o y_o) + \frac{b}{2a}\delta(x, x_o) - \frac{T_o}{2a\varepsilon_1}\delta \operatorname{Sin}(\varphi, \varphi_o)$$

where

$$A_1 = -4a\,T_o, \qquad A_2 = b^2 + 4a\,[T_o \operatorname{Cos}\varphi_o + y_o(b + ay_o)]$$

$$\underline{K > 1}$$

$$y = \frac{-b + \varepsilon_2\sqrt{A_1 \operatorname{Cos}\varphi + A_2}}{2a}$$

$$\delta(x, x_o) = \mp\frac{\varepsilon_2}{\varepsilon_1}\frac{\sqrt{2|A_1|}}{4a}[2\delta E(\bar{K}; \bar{\psi}, \bar{\psi}_o) - \delta F(\bar{K}; \bar{\psi}, \bar{\psi}_o)]$$

$$\delta(\ell, \ell_o) = \pm\frac{\varepsilon_2}{\varepsilon_1}\frac{K\sqrt{2|A_1|}}{4a}\delta F(\bar{K}; \bar{\psi}, \bar{\psi}_o) \qquad (23)$$

$$\delta(s, s_o) = \delta(xy, x_o y_o) + \frac{b}{2a}\delta(x, x_o) - \frac{T_o}{2a\varepsilon_1}\delta \operatorname{Sin}(\varphi, \varphi_o) - \frac{g_o}{2a\varepsilon_1}[\delta(\ell, \ell_o) + \delta(y, y_o) \operatorname{Sin}\varphi]$$

In sets of equations (19), (20), (22), and (23), when $A_1 > 0$ the upper sign prevails, and $\psi = \varphi/2$; if $A_1 < 0$ the lower sign prevails and

$$^4\psi = \frac{(?) - \varphi}{2}$$

---

[4][The character (?) in the original report was illegible.]

5. $a \to 0, \quad g_o \to 0$

$$\delta(y, y_o) = \frac{T_o \delta \operatorname{Cos}(\varphi, \varphi_o)}{b}$$

$$\delta(x, x_o) = \frac{T_o}{\varepsilon_1 b} \delta \operatorname{Sin}(\varphi, \varphi_o) \qquad (24)$$

$$\delta(\ell, \ell_o) = \frac{T_o}{b\varepsilon_1} \delta(\varphi, \varphi_o)$$

$$\delta(s, s_o) = \frac{1}{b}\left\{\left(\frac{1}{\varepsilon_1 b} \operatorname{Sin} \varphi_o - x_o\right) \delta \operatorname{Cos}(\varphi, \varphi_o) + \frac{1}{2b\varepsilon_1}\left[\delta(\varphi, \varphi_o) - \frac{\delta \operatorname{Sin}\cdot(2\varphi, 2\varphi_o)}{2}\right]\right\}$$

The analytical methods of designing flexible hydrotechnical structures are complex and require definite computer application. For broader application of the above results with sufficient accuracy, one can use graph analytical design methods, whose main advantages are simplicity and clarity of representation.

In analytical graph-design methods, the integral curve is presented as a smooth curve, consisting of circular arcs, assuming the radius of curvature within an infinitesimal interval to be a constant.

The design equation for determining the radii of curvature of a massive cylindrical shell, derived by V.A. Volosukhin, appears as follows:

$$R = \frac{T_o + g_o y}{2ay + b + g_o \dfrac{-ay^2 - by - c}{T_o + g_o y}} \qquad (25)$$

where

a and b are coefficients,
g_o is the weight of 1 m^2 of shell material,
T_o is the linear transverse stress in point 0 ($x = o$, $y = 0$), and
c is the constant of integration.

Without allowing for the deadweight of the shell ($g_o = 0$), equation (25) takes on the simple form of $R = 1/(2ay + b)$ or $R = T/P$, where P is the pressure in the point.

The calculation sequence for a massive cylindrical shell using the graph analytical method is as follows:

1. Given the height of the shell H, excess pressure P_o in inflatable and certain composite structures, height of layer of upper filler h_1 in shells with combined filler, thickness of overflow h_2, vertical distance from crest of shell to tailwater level h_{3t}, weight densities of the fillers γ_o, γ_1, γ_2, and γ_3, the terminal angle φ_5 at the attachment joint, and the weight of 1 m^2 of material.

2. The plots are used to determine the hydrodynamic pressure on the crest of the dam Z_o, and the hypothetical distance h_{3t} from the crest of the dam to the tailwater level TW.

3. Compute the linear stress T_o at the origin, coefficients a and b as functions of the external load, the radius of curvature R, having first divided the shell along its height into intervals Δy (10 to 15).

4. Along the analytically determined radii of curvature, construct a smooth curve consisting of circular arcs.

5. The requisite geometric characteristics are taken from the diagram.

As an example, examine the modeling of the flexible structures illustrated on figures 5 and 6.

Water- and Air-Filled Gate (fig. 5a)

Given: $H = 2.0$ m $P_o = 1.2\ t/m^2$ $h_1 = 1.0$ m $h_2 = 0.4$ m $\gamma_o = 0$

The nomograph is used to determine the following [27]:

$Z_o = 0.25$ m $h_{3f} = 1.7$ m

The coefficients Z_o, α, and β are determined according to the following relationships:

$$Z_o = \frac{Z_o \cdot H}{H + h_2 - Z_o} = \frac{0.25 \cdot 2.0}{2.0 + 0.4 - 0.25} = 0.232558$$

$$\alpha = \frac{H + h_2}{Z_o' + H} = \frac{2.0 + 0.4}{0.232558 + 2.0} = 1.07500$$

$$\beta = \frac{Z_o}{h_{3f}} = \frac{0.25}{1.7} = 0.147058$$

The linear transverse stress developing in the shell is found by the equation:

$$T_o = \frac{2P_oH + \gamma_1 (H - h_1)^2 - \gamma_2 Z_o h_{3f} - \gamma_3 (H - h_{3f})^2}{2 (\text{Cos } \varphi_5 - \text{Cos } \varphi_o)}$$

$$T_o = \frac{2 \cdot 1.2 \cdot 2.0 + 1 (2 - 1)^2 - 1 \cdot 0.25 \cdot 1.7 - 1.0 (2.0 - 1.7)^2}{2 (1 + 1)} = 1.32125$$

The radii of curvature of the shell are determined by segments according to the equation:

$$R = \frac{1}{2ay + b}$$

Segment OA

$$a = -\frac{\gamma_o - \gamma_2 \alpha}{2T_o} = -\frac{0 - 1.0 \cdot 1.07500}{2 \cdot 1.32125} = 0.406811\ m^{-2}$$

$$b = \frac{P_o - \gamma_2 Z_o}{T_o} = \frac{1.2 - 1.0 \cdot 0.25}{1.32125} = 0.719016\ m^{-1}$$

$$R_1 = \frac{1}{2.0 \cdot 0.406811 (-0.1) + 0.719016} = 1.568248\ m$$

$$R_2 = \frac{1}{2.0 \cdot 0.406811 (-0.3) + 0.719016} = 2.105573\ m$$

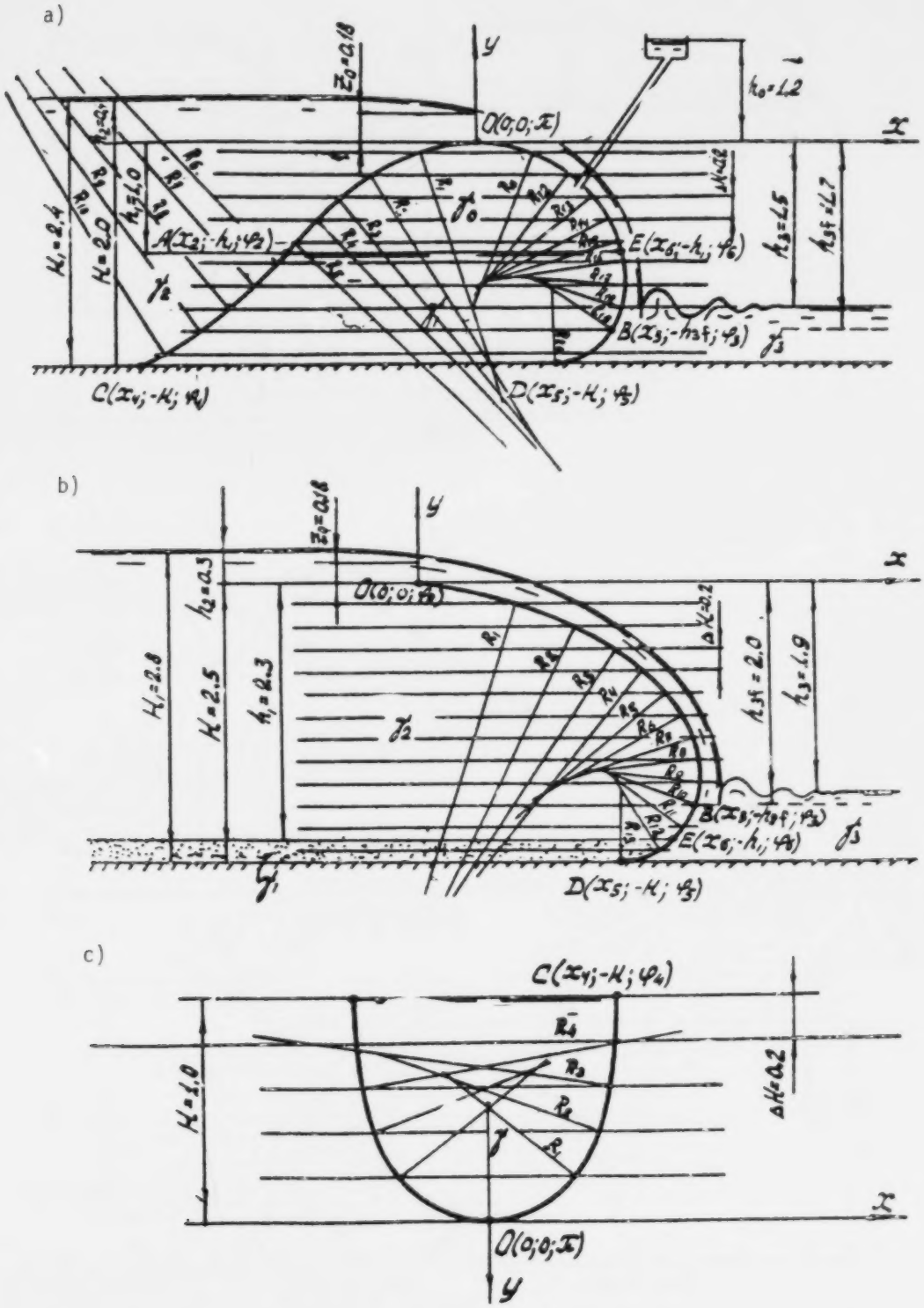

Figure 5. – Design diagrams for graph analytic method: a) water- and- air-filled dams, b) membrane dams, c) flumes.

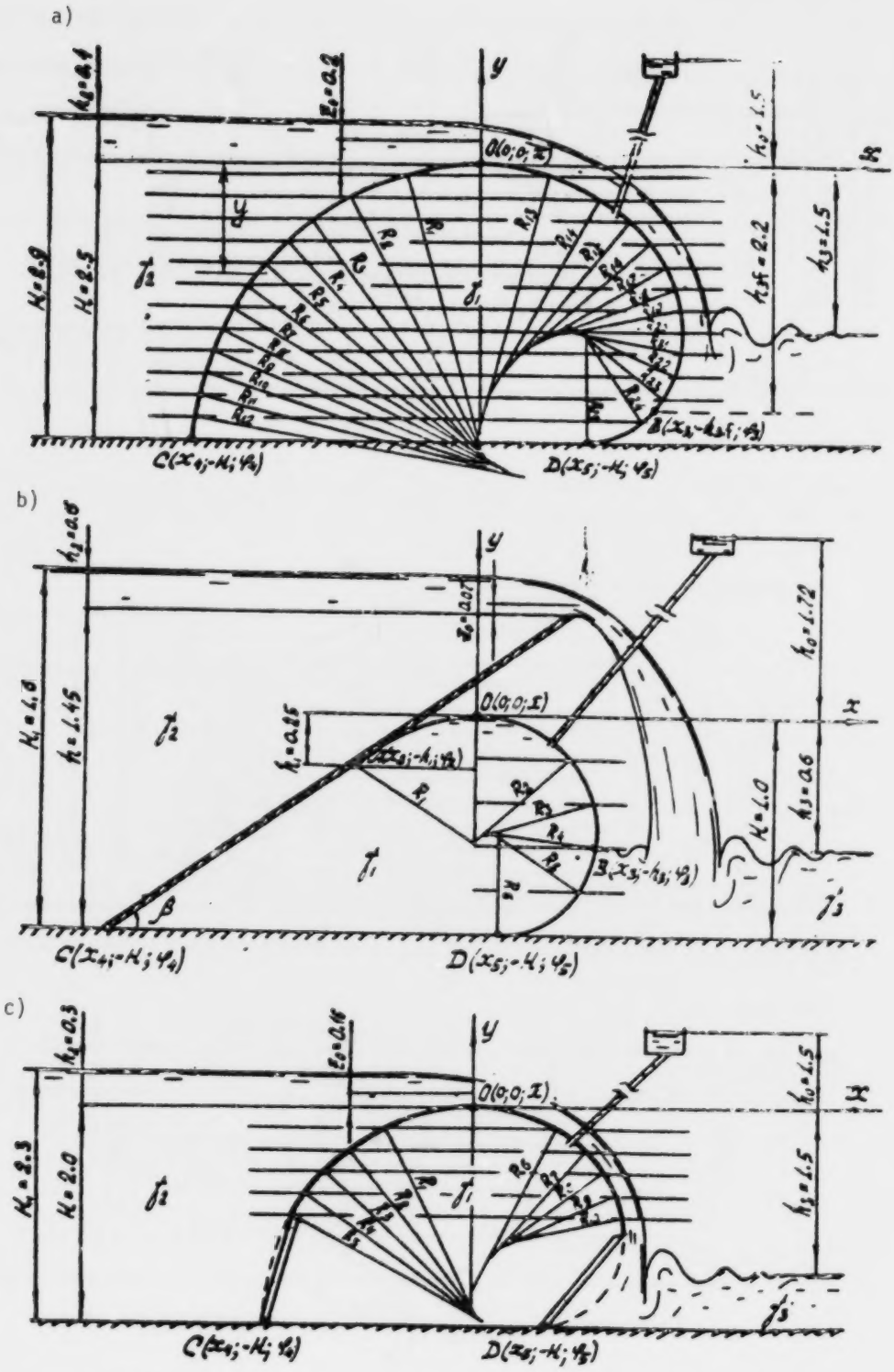

Figure 6. – Design diagrams for graph analytic method: a) water-filled dams, b) gates with a pressure shield, c) gates with floating doors.

$$R_3 = \frac{1}{2.0 \cdot 0.406811\ (-0.5) + 0.719016} = 3.203023 \text{ m}$$

$$R_4 = \frac{1}{2.0 \cdot 0.406811\ (-0.7) + 0.719016} = 6.689813 \text{ m}$$

$$R_5 = \frac{1}{2.0 \cdot 0.406811\ (-0.9) + 0.719016} = 7.5 \text{ m}$$

Segment AC

$$a = -\frac{\gamma_1 - \gamma_2\,\alpha}{2T_o} = -\frac{1.0 - 1.0 \cdot 1.07500}{2 \cdot 1.32125} = 0.028382 \text{ m}^{-2}$$

$$b = \frac{P_o - h_1\,(\gamma_1 - \gamma_o) - \gamma_2\,Z_o}{T_o} = \frac{1.2 - 1.0\,(1.0 - 0) - 1.0 \cdot 0.25}{1.32125} = -0.037842 \text{ m}^{-1}$$

$$R_6 = \frac{1}{2 \cdot 0.028382\ (-1.1) + (-0.037842)} = -9.971879 \text{ m}$$

$$R_7 = \frac{1}{2 \cdot 0.028382\ (-1.3) + (-0.037842)} = -8.957764 \text{ m}$$

$$R_8 = \frac{1}{2 \cdot 0.028382\ (-1.5) + (-0.037842)} = -8.130874 \text{ m}$$

$$R_9 = \frac{1}{2 \cdot 0.028382\ (-1.7) + (-0.037842)} = -7.443799 \text{ m}$$

$$R_{10} = \frac{1}{2 \cdot 0.028382\ (-1.9) + (-0.037842)} = -6.863747 \text{ m}$$

Segment CE

$$a = -\frac{\gamma_o + \gamma_2\,\beta}{2T_o} = -\frac{0 + 1.0 \cdot 0.147058}{2 \cdot 1.32125} = -0.055651 \text{ m}^{-2}$$

$$b = \frac{P_o - \gamma_2\,Z_o}{T_o} = \frac{1.2 - 1.0 \cdot 0.25}{1.32125} = 0.719016 \text{ m}^{-1}$$

$$R_{11} = \frac{1}{2 \cdot 0.055651 \cdot (-0.1) + 0.719016} = 1.369589 \text{ m}$$

$$R_{12} = \frac{1}{2 \cdot 0.055651 \cdot (-0.3) + 0.719016} = 1.329069 \text{ m}$$

$$R_{13} = \frac{1}{2 \cdot 0.055651 \cdot (-0.5) + 0.719016} = 1.290877 \text{ m}$$

$$R_{14} = \frac{1}{2 \cdot 0.055651 \cdot (-0.7) + 0.719016} = 1.252929 \text{ m}$$

$$R_{15} = \frac{1}{2 \cdot 0.055651 \cdot (-0.9) + 0.719016} = 1.22072 \text{ m}$$

Segment EB

$$a = -\frac{\gamma_1 + \gamma_2\,\beta}{2T_o} = -\frac{1 + 1 \cdot 0.147058}{2 \cdot 1.32125} = -0.434080 \text{ m}^{-2}$$

$$b = \frac{P_o - h_1(\gamma_1 - \gamma_o) - \gamma_2 Z_o}{T_o} = \frac{1.2 - 1.0(1.0 - 0) - 1.0 \cdot 0.25}{1.32125} = -0.37842 \text{ m}^{-1}$$

$$R_{16} = \frac{1}{2 \cdot 0.434080(-1.1) - 0.037842} = 1.090353 \text{ m}$$

$$R_{17} = \frac{1}{2 \cdot 0.434080(-1.3) - 0.037842} = 0.916787 \text{ m}$$

$$R_{18} = \frac{1}{2 \cdot 0434080(-1.5) - 0.037842} = 0.79089 \text{ m}$$

$$R_{19} = \frac{1}{2 \cdot 0.434080(-1.7) - 0.037842} = 0.695396 \text{ m}$$

Segment BD

$$a = -\frac{\gamma_1 - \gamma_3}{2T} = -\frac{1 - 1}{2 \cdot 1.32125} = 0$$

$$b = \frac{P_o - h_1(\gamma_1 - \gamma_o) + \gamma_3 h_{3\prime}}{T} = \frac{1.2 - 1.0(1.0 - 0) + 1.0 \cdot 1.7}{1.32125} = 1.438032 \text{ m}^2$$

$$R_2 = \frac{1}{b} = \frac{1}{1.438032} = 0.695394 \text{ m}$$

Membrane gate

Given: $H = 2.5$ m $h_1 = 2.3$ m $h_2 = 0.3$ m $h_3 = 1.9$ m
$\varphi_o = 170°$ $\varphi_5 = 0°$ $\gamma = 1.8$ t/m³ $\gamma_2 = \gamma_3 = 1.0$ t/m³

The nomograph [34] is used to determine

$$Z_o = 0.18 \text{ m} \quad h_{3\prime} = 2.0 \text{ m}$$

Coefficient β is determined from the equation:

$$\beta = \frac{Z_o}{h_{3\prime}} = \frac{0.18}{2.0} = 0.09$$

The total transverse stress developing within the shell is determined by the equation:

$$T_o = \frac{\gamma_1(H - h_1)^2 + \gamma_2(H_1 + h_2)H - \gamma_2 Z_o h_{3\prime} - \gamma_3(H - h_{3\prime})^2}{2(\cos\varphi_5 - \cos\varphi_o)}$$

$$^5T_o = \frac{1.8(2.5 - 2.3)^2 + 1.0(2.8 + 0.3)2.5 - 1.0 \cdot 0.18 \cdot 2.0 - 1.0(2.5 - 2.0)^2}{2(1 + 1)} = 1.832377 \text{ t/m}$$

Segment OB

$$a = \frac{\gamma(1.0 + \beta)}{2T} = -\frac{1.0(1.0 + 0.09)}{2 \cdot 1.832377} = -0.297427 \text{ m}^{-2}$$

---

[5] Based on the figures used in the original Russian, there is an error in the calculations.

$$b = \frac{\gamma_2 (h_2 - Z_o)}{T} = \frac{1\ (0.3 - 0.18)}{1.832377} = 0.065488\ m^{-1}$$

Assigning the values of a, b, T, and y (for the middle of the segments in question: -0.1, -0.3, -0.5, -0.7, -0.9, -1.1, -1.3, -1.5, -1.7, -1.9), obtain the corresponding values of the radii of curvature on segment OB:

$R_1 = 8.001645$ m $\quad R_2 = 4.099276$ m $\quad R_3 = 2.755453$ m $\quad R_4 = 2.075170$ m
$R_5 = 1.664283$ m $\quad R_6 = 1.389216$ m $\quad R_7 = 1.192177$ m $\quad R_8 = 1.192177$ m
$R_9 = 0.928726$ m $\quad R_{10} = 0.836319$ m

Segment EB

$$a = -\frac{\gamma_2 - \gamma_3}{2T} = -\frac{1.0 - 1.0}{2 \cdot 1.832377} = 0$$

$$b = \frac{\gamma_2 h_2 + \gamma_3 h_{3'} - \gamma_1 h_1}{T} = \frac{1.0 \cdot 0.03 + 1 \cdot 2.0}{1.832377} = -1.2552\ m^{-1}$$

$$R_{11} = \frac{1}{1.255200} = 0.796685\ m$$

Segment BD

$$a = -\frac{\gamma_1 + \gamma_2 - \gamma_3}{2T} = -\frac{1.8 - 1.0 - 1.0}{2 \cdot 1.832377} = \frac{-0.2}{3.664754} = -0.491165\ m^{-2}$$

$$b = \frac{\gamma_2 h_2 + \gamma_3 h_{3'} - \gamma_1 h_1}{T} = \frac{1 \cdot 0.3 + 1 \cdot 2.0 - 1.8 \cdot 2.3}{1.832377} = -1.004160\ m^{-1}$$

$$R_{12} = \frac{1}{2 \cdot (0.491165) \cdot (-2.3) - 1.004160} = 0.712986\ m$$

Membrane Flume (fig. 5.c)

Given: $H = 1.0$ m $\quad \gamma = 1$ t/m^3 $\quad \varphi_4 = 90°$ $\quad \varphi_o = \pi$

The linear transverse stress on the shell is determined by the equation:

$$T = \frac{\gamma H_2}{2\ (\mathrm{Cos}\ \varphi_4 - \mathrm{Cos}\ \varphi_o)} = \frac{1 \cdot 1^2}{2\ (1 - 0)} = 0.5\ t/m$$

Segment OC

$$a = \frac{\gamma}{2T} = \frac{1.0}{2 \cdot 0.5} = 1\ m^{-2}, \quad b = \frac{\gamma \cdot H}{T} = \frac{1 \cdot 1}{0.5} = 2.0\ m^{-1}$$

$$R_1 = \frac{1}{2 \cdot 1\ (-0.1) + 2.0} = 0.55555\ m$$

$$R_2 = \frac{1}{2 \cdot 1\,(-0.3) + 2.0} = 0.714285 \text{ m}$$

$$R_3 = \frac{1}{2 \cdot 1\,(-0.5) + 2.0} = 1.00000 \text{ m}$$

$$R_4 = \frac{1}{2 \cdot 1\,(-0.7) + 2.0} = 1.66666 \text{ m}$$

$$R_5 = \frac{1}{2 \cdot 1\,(-0.9) + 2.0} = 5.00000 \text{ m}$$

On segment *OD* the radii are symmetrically equal to the radii of *OC*.

Water-Filled Gate (fig. 6a)

Given: $P_o = 1.5$ t/m² $\quad H = 2.5$ m $\quad h_2 = 0.4$ m $\quad h_3 = 1.5$ m
$\gamma_1 = \gamma_2 = \gamma_3 = 1.0$ t/m³ $\quad \varphi_o = \pi \quad \varphi_5 = 0$

Determine: $Z_o = 0.2$ m $\quad h_{3'} = 2.20$ m

$$\beta = \frac{Z_o}{h_{3'}} = \frac{0.2}{2.2} = 0.090909$$

$$Z_o' = \frac{Z_o \cdot H}{H + h_2 - Z_o} = \frac{0.2 \cdot 2.5}{2.5 + 0.4 - 0.2} = \frac{0.5}{2.7} = 0.185185$$

$$\alpha = \frac{H + h_2}{Z_o + H} = \frac{2.5 + 0.4}{0.185185 + 2.5} = 1.080$$

$$T = \frac{2P_oH + \gamma_1 \cdot H^2 - \gamma Z_o\, h_{3'} - \gamma_3\,(H - h_{3'})^2}{2\,(\text{Cos}\,\varphi_5 - \text{Cos}\,\varphi_o)}$$

$$T = \frac{2 \cdot 1.5 \cdot 2.5 + 1 \cdot 2.5^2 - 1 \cdot 0.2 \cdot 2.2 - 1(2.5 - 2.2)^2}{2\,(1 + 1)} = 3.305 \text{ t/m}$$

$$a = -\frac{\gamma_1 - \gamma_2\,\alpha}{2T} = -\frac{1 - 1 \cdot 1.080}{2 \cdot 3.3050} = 0.012102 \text{ m}^{-2}$$

$$b = \frac{P_o - \gamma_2 Z_o}{T} = \frac{1.5 - 1.02}{3.3050} = 0.393343 \text{ m}^{-1}$$

Substituting in the equation for the radius of curvature values from −0.1 to −2.3 at intervals of 0.2, obtain:

$R_1 = 2.558804$ m	$R_2 = 2.590123$ m	$R_3 = 2.633012$ m	$R_4 = 2.656741$ m
$R_5 = 2.691355$ m	$R_6 = 2.726883$ m	$R_7 = 2.763362$ m	$R_8 = 2.800830$ m
$R_9 = 2.839320$ m	$R_{10} = 2.877790$ m	$R_{11} = 2.919580$ m	$R_{12} = 2.961436$ m
	$R_{13} = 2.993617$ m		

Segment OB

$$a = -\frac{\gamma_1 + \gamma_2\beta}{2T} = \frac{1 + 1 \cdot 0.090909}{2 \cdot 3.305} = -0.165039 \text{ m}^{-2}$$

$$b = \frac{P_o - \gamma_2 Z_o}{T} = \frac{1.5 - 1 \cdot 0.2}{3.305} = 0.393343 \text{ m}^{-1}$$

then

$R_{14} = 2.345490$ m $\quad R_{15} = 2.031009$ m $\quad R_{16} = 1.790888$ m $\quad R_{17} = 1.601545$ m
$R_{18} = 1.448408$ m $\quad R_{19} = 1.322002$ m $\quad R_{20} = 1.215888$ m $\quad R_{21} = 1.125432$ m
$R_{22} = 1.047696$ m $\quad R_{23} = 0.979920$ m $\quad R_{24} = 0.920381$ m

Segment BD

$$a = -\frac{\gamma_1 - \gamma_3}{2T} = \frac{1 - 1}{2 \cdot 3.3050} = 0$$

$$b = \frac{P_o + \gamma_3 \cdot h_3}{T} = \frac{1.5 + 1 \cdot 2.2}{3.3050} = 1.119515 \text{ m}^{-1}$$

$$R_{25} = \frac{1}{1.119515} = 0.893243 \text{ m}$$

Inflatable Gate With Pressure Shield (fig. 6b)

Given: $H = 1.0$ m $\quad h_1 = 0.25$ m $\quad h_2 = 0.15$ m $\quad h_3 = 0.6$ m $\quad \ell = 2.53$ m
$\beta = 35°$ $\quad Z_o = 0.07$ m $\quad \gamma_1 = \gamma_2 = \gamma_3 = 1$ t/m^3 $\quad \varphi_s = 0°$
$\varphi_o = 0°$ $\quad h = \ell \sin \beta = 1.45$ m $\quad H_1 = 1.45 + 0.15 = 1.60$ m

$$P_o = \frac{\gamma_2 h^2 (H_1 - Z_o) + 3 \gamma_2 Z_o h^2 + 1.50 h \cdot \sin 2\beta - 3\gamma_1 h_1 (H - h_1)^2 - \gamma_1 (H - h_1)^3}{3 (H - h_1)^2}$$

$$P_o = \frac{1 \cdot 1.45^2 (1.6 - 0.07) + 3.1 \cdot 0.07 \cdot 1.45^2 + 1.5 \cdot 0.07 \cdot 0.93971 - 3 \cdot 1 \cdot 0.25 (1 - 0.25)^2 - 1 (1 - 0.25)^3}{3 (1 - 0.25)^2}$$

$= 1.726380$ ton/m^2

$$T = \frac{\gamma_2 \cdot H^2 + 2 \cdot P_o H - \gamma_3 (H - h_3)^2}{2 (\text{Cos } \varphi_s - \text{Cos } \varphi_o)} = \frac{1 \cdot 1^2 + 2 \cdot 1.726380 \cdot 1 - 1(1 - 0.6)^2}{2 (1 + 1)} = 1.07319 \text{ t/m}$$

Segment OA

$$a = -\frac{\gamma_1}{2T} = -\frac{1}{2 \cdot 1.07319} = -0.465900 \text{ m}^2$$

$$b = \frac{P_o}{T} = \frac{1.726380}{1.07319} = 1.608643 \text{ m}^{-1}$$

$$R_1 = \frac{1}{2 \cdot (-0.465900) \cdot (-0.125) + 1.608643} = 0.579670 \text{ m}$$

Segment OB

$$a_2 = -\frac{\gamma_1}{2T} = -\frac{1}{2 \cdot 1.07319} = -0.46590 \text{ m}^{-2}$$

$$b_2 = \frac{P_o}{T} = \frac{1.726380}{1.07319} = 1.608643 \text{ m}^{-1}$$

$$R_2 = \frac{1}{2 \cdot (-0.465900)(-0.1) + 1.608643} = 0.587605 \text{ m}$$

$$R_3 = \frac{1}{2 \cdot (-0.465900)(-0.3) + 1.608643} = 0.529609 \text{ m}$$

$$R_4 = \frac{1}{2 \cdot (-0.465900)(-0.5) + 1.608643} = 0.482033 \text{ m}$$

Segment BD

$$a = -\frac{\gamma_1 - \gamma_3}{T} = \frac{1 - 1}{1.07319} = 0$$

$$b = \frac{P_o - h_1(\gamma_1 - \gamma_2) - \gamma_3 h_{3y}}{T} = \frac{1.72638 - 0.25(1 - 1) + 1.06}{1.07319} = 2.59 \text{ m}^{-1}$$

$$R_2 = \frac{1}{b} = \frac{1}{2.59} = 0.386 \text{ m}$$

Inflatable Gate With Floating Doors (fig. 6c)

$P_o = 1.5$ t/m² $\quad H = 2.0$ m $\quad h_2 = 0.3$ m $\quad h_3 = 1.5$ m $\quad Z_o = 0.16$ m

$\gamma_1 = \gamma_2 = \gamma_3 = 1.0$ t/m³ $\quad \varphi_o = \pi \quad \alpha_5 = 0 \quad h_{3y} = 1.75$ m

$$\beta = \frac{Z_o}{h_{3y}} = \frac{0.16}{1.75} = 0.091428 \text{ m}$$

$$Z_o' = \frac{Z_o H}{H + h_2 - Z_o} = \frac{0.16 \times 2.0}{2.0 + 0.3 - 0.16} = 0.150$$

$$\alpha = \frac{H + h_2}{Z_o' + H} = \frac{2.0 + 0.3}{0.150 + 2.0} = 1.07$$

$$T = \frac{2P_o H + \gamma_1 H^2 - \gamma Z_o h_{3y} - \gamma_3 (H - h_{3y})^2}{2(\text{Cos } \varphi_5 - \text{Cos } \varphi_o)}$$

$$T = \frac{2 \cdot 1.5 \cdot 2.0 + 1.2^2 - 1 \cdot 0.16 \cdot 1.75 - 1(2.0 \cdot 1.95)^2}{2(1 + 1)} = 2.414375 \text{ t/m}$$

Segment OC

$$a = -\frac{\gamma_1 - \gamma_2 \alpha}{2T} = -\frac{1 - 1 \cdot 1.070}{2 \cdot 2.414375} = 0.014496 \text{ m}^{-2}$$

$$b = \frac{P_o - \gamma_2 Z_o}{T} = \frac{1.5 - 1 \cdot 0.16}{2.414375} = 0.555009 \text{ m}^{-1}$$

$R_1 = 1.811233$ m $\quad R_2 = 1.830455$ m $\quad R_3 = 1.850094$ m $\quad R_4 = 1.870155$ m
$R_5 = 1.890655$ m

Segment OB

$$a = -\frac{\gamma_1 + \gamma_2 \beta}{2T} = \frac{1 + 1 \cdot 0.091428}{2 \cdot 2.414375} = -0.226027 \text{ m}^{-2}$$

$$b = \frac{P_o - \gamma_o Z_o}{T} = \frac{1.5 - 1 \cdot 0.16}{2.414375} = 0.555009 \text{ m}$$

$R_6 = 1.666072$ m $R_7 = 1.447963$ m $R_8 = 1.280350$ m $R_9 = 1.147518$ m
$R_{10} = 1.039655$ m

HYDRAULIC CALCULATIONS

From the standpoint of hydraulics, the whole spectrum of design solutions for check structures consisting of flexible shells can be divided into spillways of practical profile (inflatable and membrane types, for which $\varphi_2 = 140°$ to 180°) and thin shell spillways[6] (rectilinear and inclined for composite types, and curvilinear for the membrane types). Here it should be noted that these spillways, moreover, are of the "vacuum" type due to the presence of a negative pressure zone on the downstream face.

Depending on the crest configuration of the spillway wall in the plan view, flexible structure scan be subdivided, as in the case of rigid spillways, into:

- Spillways with a rectilinear crest of the overflow wall which are classified according to their location as direct, oblique, and lateral.
- Spillways with an overflow wall crest rectilinear in the plan view, subdivided in turn in the plan view into polygonal, curvilinear, and circular.

Depending on the influence of the tailwater on discharge, spillways can be nonsubmerged when Q and H do not depend on submergence h_n, and submerged when Q and H depend on h_n.

Also, in the case of rectangular spillways, depending on the relationship between the width of the spillway and the upstream channel, it is necessary to differentiate spillways without side contractions ($B_b = b$) and spillways with side contractions ($B_b > b$).

It should be noted that questions concerning the discharge capacity of spillways made from flexible materials have not been fully answered, even for those structures that are already in fairly widespread use in the field, not to mention those promising designs of check structures that can be manufactured from flexible materials. Hydraulic studies of such spillways are hampered by a great number of problems because their configurations, linear dimensions, etc., are functions of the headwater and tailwater levels, means of attachment, type of filler, and consequently, the hydraulic parameters that characterize them are functions of these quantities.

In here, some data for calculating the discharge capacity of inflatable and membrane-type spillways are given.

Certain recommendations derived for standard (traditional) spillways can be applied, in the first approximation, to calculations of the discharge capacity of flexible spillways.

Generally, the discharge capacity of a spillway is calculated according to the equation:

$$Q = \sigma_n \varepsilon m B \sqrt{2g} H_o^{3/2} \qquad (26)$$

where

B = effective length of crest, $B = \Sigma b$ (for a single spillway $B = b$)
σ_n = submergence coefficient
ε = side contraction coefficient
H_o = total head on spillway crest, including velocity of approach head
m = coefficient of discharge

Analysis of the results from experimental investigations of inflatable spillways has shown that the coefficient of discharge varies over a wide range depending on head, internal pressure within the spillway shell, as well as on the shape and type of discharge over (through) the spillway.

Thus;

m = 0.300 to 0.510 for uncontrolled discharge over a water-filled spillway
m = 0.387 to 0.554 for an air-filled spillway
m = 0.360 to 0.564 for a water- and air-filled spillway

Here, the lower coefficients of discharge correspond to lower heads and the higher values correspond to higher heads and internal pressures.

[6]Also can be "sharp-crested weir."

In the case of submerged overflow, the coefficients of discharge are:

- 0.470 to 0.290 for water-filled spillways
- 0.533 to 0.321 for air-filled spillways
- 0.510 to 0.250 for water- and air-filled spillways

The lower values of the coefficient of discharge for air-filled spillways correspond to higher heads but lesser drops between headwater and tailwater. The pattern is the same for air-filled spillways but at rather high internal pressure (gauge pressure $P_o/\gamma \geq 1.5 \div 2H$).

Upon a decrease in internal pressure, the spillway shell conforms to the headwater level, thereby maintaining almost constant head on the spillway crest. Greater coefficients of discharge are obtained, however, when the tailwater level is similar to the crest height of the spillway (see fig. 5b).

The coefficient of discharge is greatly influenced by the tailwater level only when it exceeds the crest height of the spillway. In this case, the ratio of the drop from headwater to tailwater to head Z/H = 0.6 to 0.25, and the flow in the tailwater becomes a surface flow. In the case of a further rise in the tailwater level, the headwater-tailwater transition becomes a wave jump. First, a single wave is formed and then with a decrease in the drop, several waves are formed, the sizes of which decrease along the direction of flow.

The coefficient of discharge of a flexible inflatable spillway can be determined according to the equations derived by Cand. Tech. Sci. A.P. Nazarov [34] or approximated according to Prof. P.M. Stepanov's equation, obtained on the basis of Nazarov's experimental data:

$$0.416 \left[\ln \left(\frac{H_1}{C_{in}} \right) + 1.2 \ln \left(\frac{C_{in}}{D} \right) + 0.877 \right] \quad (27)$$

where

m = 2.718
H_1 = headwater depth
C_{in} = original height of spillway
D = arbitary diameter of shell if the spillway had, along its periphery, a configuration such that $D = L/\pi$

The rather high values of the coefficient of discharge, besides the streamlined shape of the spillway, are explained as well by the presence of a subatmospheric pressure zone on its downstream face. With an increase in discharge, and consequently of head, this zone is shifted along the overflow face upward towards the spillway crest. On the spillway crest the pressure becomes equal to atmospheric. In the presence of submerged flow, a zone of subatmospheric pressure also is observed, but it gradually diminishes as the tailwater level is raised, finally disappearing altogether. Thus, in the case of an uncontrolled overflow as well as a partially submerged overflow, a flexible inflatable spillway functions as a "vacuum" spillway.

Evidently, one of the causes of vibration of a spillway shell is the presence of the negative pressure, within the region of which it is as if the shell bulges, thus causing momentary redistribution of the transverse stress and diminished curvature. At the same time, the external pressure and vacuum are changed, thus setting up a vibration within the shell.

This vibration is amplified as discharge and head increase. Maximum vibration sets in at the moment the flow in the tailwater becomes a surface flow. If the tailwater level is raised above the spillway crest level, the vibration dies out. The negative pressures and amplitudes as well as frequency of vibrations depend on discharge intensity, internal pressure within the shell, the type of overflow, and other parameters of the flow.

The discharge capacity of the membrane-type spillways was first studied by Can. Tech. Sci. V.L. Bondarenko. Analysis of experimental data showed that, depending on the angle φ_2 formed by a tangent to the crest of the spillway and the horizontal, the spillway takes on the shape of a sharp-crested curvilinear weir or an ogee profile. However, in both cases the discharge has its own unique properties. For instance, at φ_2 = 120° to 180°, an eddy forms in the headwater next to the panel, and this affects the discharge capacity.

Thus, the following discharge properties can be noted for membrane structures (fig. 5b):

- For φ_2 = 70° to 110°, the discharge is in the form of a vena contracta
- For φ_2 = 140° to 180°, the shape of the jet is analogous to flow over an ogee crest whose profile conforms to the under nappe of the overflow

- For φ_2 = 120° to 130°, the jet can be either adhering (at $H/C_b < 0.22$) or detached (at $H/C_b > 0.22$)

These studies have shown that the discharge capacity of membrane-type spillways depends on head H, the values of angle φ_2 (crest position), and the intensity and location of the subatmospheric pressure zone.

At angles φ_2 = 70° to 110°, the coefficient of discharge m rises from 0.42 and peaks at 0.52 for values of H/C_b = 0.37 to 0.43, when the vacuum under the jet is broken; the coefficient of discharge diminished upon further increase in the rato H/C_b.

At angles φ = 140° to 180°, the size of angle φ_2 greatly influences the coefficient of discharge. The discharge capacity decreases from 0.44 to 0.34 when this angle is increased. This is explained by increased losses at the approach and along its length. At the given angle φ_2, an increase in head results in an increase in the coefficient of discharge m to 0.53.

At φ_2 = 70° to 110°, the coefficient of discharge m should be computed according to the following empirical equation:

$$m = \frac{\left[\varphi_2 - \frac{\pi^4}{2} + 0.491\right]\left[0.44 - \varphi_2 - \frac{\pi^4}{2}\right]}{\left[0.44 - \left(\varphi_2 - \frac{\pi}{2}\right)^4\right]^4} - \frac{\left[\varphi_2 - \frac{\varphi^4}{2} - 0.44\right]^2}{\left[0.44 - \varphi_2 - \frac{\varphi^4}{2}\right]^4} \quad (28)$$

and for angles φ_2 = 140° to 180°

$$m = [-(\varphi_2 - 0.833\,\pi)^4 + 0.52] - \frac{\left(\frac{H}{C_b} - 0.54\,\varphi_2 + 0.94\right)^2}{n\,(0.54\,\varphi_2 - 0.94)^2} \quad (29)$$

where n is a function of φ_2 and is found from the plot given in [38].

The addition of more shells, either inflatable or membrane type, to the structure causes a 15 to 20 percent increase or decrease in the discharge capacity of the spillway, and depends on their mutual arrangement.

Composite flexible structures, as noted above, are manufactured from both flexible [nonrigid] and traditional materials. If in the structure the overflow is effected over a flexible shell, whether inflatable or membrane type, the discharge capacity is determined as over an inflatable or membrane spillway.

But if the overflow is effected through a gate, the discharge capacity of that structure is determined as for a sharp-crested weir with a crest slope correction.

As regards conveyance structures made of flexible materials, the available literature [16 and 36] demonstrates that the most advantageous section from the hydraulics standpoint, after the semicircle, is a section formed by an elliptic curve. Their discharge capacity can be determined using the hydraulic dependences and equations from the static design method [32].

SEEPAGE CALCULATIONS

The use of flexible inflatable, membrane, and composite structures requires the use of devices to act as transitions between them and the bottom and banks. In foreign practice, aprons made from traditional materials generally are used, and the shear strength and seepage properties of the structure are computed in the usual manner.

In addition to rigid aprons, flexible aprons made from flexible materials having reduced strength requirements have been developed and are recommended.

Flexible aprons are panels designated as enclosed and exposed according to the parameters of the flow: the exposed aprons are panels projecting into either the headwater or tailwater alone (functioning as a floor) or into both the headwater and tailwater, simultaneously functioning as upstream blanket and downstream spillway apron. Ordinarily, the enclosed aprons are filled with local materials (clay, sand, clay loam, etc.) and are used in different configurations with the exposed aprons.

When flexible aprons are used, seepage calculations have their own special characteristics. In contrast to a rigid apron, flexible aprons having an exposed panel operate as an elastic membrane, filling in all of the irregularities and voids in the

foundation of the structure. The material of the apron absorbs tensile stresses and neither transmits nor absorbs compressive forces.

In the initial stage of failure of foundation soil, seepage boils or piping occurs at the point of emergence of the seepage flow on the downstream slope. Then the load of the apron material on the failure region is relieved.

On account of the failure (erosion) of foundation soil from underneath the structure, the flexible apron acquires the capability of burying itself deeper, and because of this, a downstream toe is designed into the flat apron. In this case, even an unburied apron can be considered to be an apron having horizontal and vertical seepage paths. Thus, the "effective" length of the apron is increased (the length of the impervious underground contour over the extent of which head loss occurs).

This circumstances of the self-burial of the downstream part of a flexible apron ceases the moment advantageous pressure gradients corresponding to a state of equilibrium in the foundation soil are established. Consequently, it is as though the foundation were reinforced against further development of seepage deformations. This fact offers proof of the fundamental difference in the operation of flat rigid and flexible aprons.

A flexible apron having an enclosed panel, owing to its imperviousness and the overload confined within the shell, enlarges the impervious underground contour and considerably improves the shear resistance of the structure. The blanket portion of the apron protects the upstream channel from scour. Also, it should be noted that a soil-filled stilling apron, due to its slight resilience, absorbs and partially dissipates the energy of the overflowing water jet, thereby improving the hydraulic conditions in the outlet channel.

A soil-filled apron is buried in the foundation to provide sufficient seepage control in the contact zone. Moreover, for prevention of dangerous contact seepage, it is recommended that soil-filled piers designed to extend the lateral seepage paths be installed. Simple exposed panels entrenched in the banks can be used for improved connection with the banks.

Soil-filled spillway aprons or soil-filled structures can be used in various combinations, e.g., soil-filled spillway apron and upstream apron of cohesive soils (when cohesive soil is available near the construction site); soil-filled upstream blanket and concrete spillway apron (if cohesive soil is not available and it is necessary to extend the seepage paths in structures already in operation).

The task of the designer is to find the rational underground contour; i.e., a contour that satisfies the condition of static stability of the structure, the condition that dangerous seepage deformations are not allowed to develop, and still keeps the structure economical.

Selection of apron dimensions must begin with determination of the maximum length of the underground contour that provides seepage stability of the foundation soil. For soils susceptible to heaving (cohesive and sandy with a uniformity coefficient $q < 10$), it is suggested that Cand. Tech. Sci. Iu. M. Kosichenko's equation [19] be used:

$$\ell_{min} = \frac{(\gamma H k_h)^2}{12\, t_{rr}\, (\gamma_{sat} - \gamma)^2} \qquad (30)$$

where

γ = density of soil saturated with water
k_h = safety factor with respect to heaving
t_{rr} = thickness of permeable riprap, equal to apron thickness

When piping soils are present in the foundation, the minimal length of the underground contour can be found according to B.P. Ruplis' equation:

$$\lambda_c = \frac{3.66\, k_p - H}{i_{cr}} \qquad (31)$$

where

k_p = safety factor with respect to piping, which is taken equal to k_h
i_{cr} = critical gradient for the given soil

The length of the spillway apron part is found by hydraulic calculations, and then factors related to the seepage stability of the foundation are used to determine the required length of the upstream blanket:

$$\ell_{u.b.} = \ell_{min} - (\ell_h + \ell_g) \qquad (32)$$

where ℓ_g equals length of the supporting portion of the gate shell.

Finally, it is necessary to check the accepted thickness of the soil-filled apron as it relates to the shear strength of the structure along its base.

Along with this, solution of the problem of the minimum shell perimeter L is of interest for the purpose of determining the least quantity of fabric that can be used (a question of economy). It is expedient to solve this problem by applying the condition of shear strength:

$$k_c \leq \frac{f(\Sigma P - W_\varphi)}{Q} \qquad (33)$$

where

$\Sigma P = 0.9\,\gamma H(\ell - \ell_g) + \gamma_{sat}\, t\, \ell$

$W_\varphi = (1/2)\,\gamma H \ell$

$Q = (1/2)\,\gamma H^2$

0.9 = coefficient for determining ΣP, which allows for $\gamma \neq \infty$ the infinite thickness of the permeable foundation

Keeping in mind that, in simplified form, the shell perimeter equals

$$L = 2\left(\ell + \frac{\pi}{2}t\right); \quad \text{i.e., } L = f(\ell, T)$$

from which, having evaluated t and substituted it in equation (33), obtain

$$L = \frac{\frac{0.5}{f}\gamma H^2 k_c - 0.55\,\gamma H(\ell - \ell_b)}{\gamma_{sat}\,\ell^2/\pi} + \frac{0.45\,\gamma \cdot \ell_b + \frac{2\gamma_{sat}}{\pi}\ell^2}{\gamma_{sat}\,\ell^2/\pi} \qquad (34)$$

The condition[7] of minimum shell perimeter

$$\frac{dL}{dL} = 0°$$

$$\ell = [((H^2 k_c/2f) + H\ell_b)(\pi/2\gamma_{sat})]^{1/2} \qquad (35)$$

The thickness of the soil-filled apron is determined from the condition of shear resistance according to the equation:

$$t = \frac{\frac{H^2 k_c}{2f} + 0.45\,H\ell_b - 0.5\,H(\ell - \ell_b)}{\gamma_{sat}\,\ell} \qquad (36)$$

If the soil-filled shell is only used as an upstream blanket, then equations (35) and (36) for $\ell_b = 0$ take the simple form.

In the case when the soil-filled shell is only used as a downstream apron ($\ell = \ell_b$), its length is determined by hydraulic calculations, and its thickness:

$$t = \frac{H^2 k_c/(2f) + 0.45\,H\ell}{\gamma_{sat}\,\ell} \qquad (37)$$

In another particular case, when the thickness of the soil-filled apron $t = 0$ (apron consisting of an upstream blanket panel and supporting part of the shell), the length of the blanket part will be

$$\ell_{u.b} = \frac{k_c H}{1.1\,f} - \ell_3 \qquad (38)$$

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[7]Translation was unclear on this equation.

EXPERIENCE IN USING FLEXIBLE STRUCTURES

FOREIGN EXPERIENCE IN DESIGN, CONSTRUCTION, AND OPERATION OF FLEXIBLE STRUCTURES

Of the great number of flexible structures commonly used in hydrotechnical construction abroad, the most widespread are flexible inflatable gates mounted on a flat concrete apron.

The first such gate (manufactured by the Firestone Tire and Rubber Company under the tradename "Imbertson fabridam") was installed by the Los Angeles Department of Water and Power on the Los Angeles River in 1959.

Southern California, where the Los Angeles River flows, is one of the most arid regions in the U.S.A. The minimum streamflows do not satisfy the demands of the nearby cities, much less those of the surrounding irrigated land. Therefore, a long time ago, temporary check dams (most frequently wooden) were constructed on the lower reaches of the river, thus creating reserves of water for drinking and irrigation purposes.

Floods frequently washed away the wooden dams, and the runaway waters inflicted colossal damage; then at lower water, there again was insufficient supply and the dams had to be rebuilt. Moreover, the region at the mouth of the Los Angeles River is subject to severe winter storms, which not only destroyed the dams, but also drove masses of ocean water up the river channel, causing heavy winter floods.

The answer was the "Fabridam" flexible gate 46-meters across and 1.72-meters high, a check structure that would solve three problems at once — replenishment of ground-water supplies, protection of the surrounding area from devastating floods, and elimination of great outlays of money for restoration of the ruined wooden dams. The shell withstands the abrasive action of sediments and is filled with water to its maximum height (through a coupling sleeve passing through the canal wall) within 25 minutes—taking 190 m^3 of water. For this reason, this gate is unique in its flexibility. When the shell is filled to its design capacity, the gate operates similarly to the concrete structure of a fixed crest weir [blind weir or non-overflow dam]. At the same time, when the shell is completely flattened, the gate offers minimal resistance to the flow, assuring maximum discharge in the section line during flooding.

To provide automatic deflation of the gate (in case of flooding), a siphon device was installed which is connected to a waterpipe 5.5-meters long and situated in the basin together with the gate. The water pressure inside the shell (which also results from the water pressure in the river) is transmitted to the water inside the pipe. The pipe terminates in the siphon device, which is adjusted to a certain height, and if the pressure within the shell rises to a certain value, the siphon is activated and the shell is emptied of water.

The principal advantage of the gate is that the deflation cycle of the gate shell is initiated and controlled without the use of electrical energy, mechanical drives, or complex control systems, which provides operational reliability heretofore unknown in control structures.

The gate shell was made of material produced by the Firestone Company; it is 3.18-millimeters thick with two plys of reinforcement fabric and is impregnated with neoprene rubber. A strip of such material 1 meter wide can take a load of 8930 kilograms without tearing.

The cost of erecting the gate was $10,000 which was approximately the same as the annual expenditures for repair and maintenance of the earlier wooden dam. The yearly conservation of 2 500 000 m^3 of water due to the service of the structure is worth ca. $75,000.

In Europe, the first gate of this type was constructed in 1961 in France on the Vézère River near the town of Objat (fig. 7). The Objat Hydroelectric Powerplant on the Vézère was equipped with a flexible gate at the base of an old concrete dam, the crest of which was situated approximately 2 meters high than the tailwater. On studying the surroundings and stability of the structure,

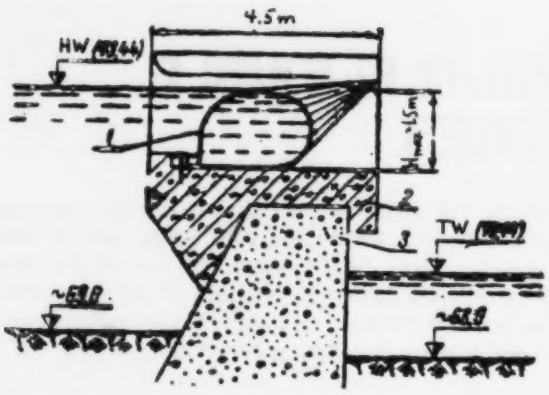

Figure 7. – Flexible dam on the Vézère River (France). (1) flexible shells, (2) concrete base, (3) previously existing dam.

it was deemed possible to raise the water level another 1.4 meters, which was equivalent to increasing the power output by 1000 kilowatts.

However, it was out of the question to think of a stable water surface elevation because the Vézère, flowing down from the Central Massif to the Dordogne River, has a most unstable discharge.

While the minimum flow is 50 to 60 m^3/s, the spring runoff measures 400 to 500 m^3/s, and in extreme instances, it even exceeds 1000 m^3/s. Under such circumstances, the use of a concrete dam of great height would endanger the nearby agricultural lands even in the event of a moderate flood. Consequently, only a portable structure could be used, one that could be entirely removed in case of high water.

The problem of a mobile structure could have been solved by traditional means (metal gates or valves), but their construction costs were much greater than for a flexible gate.

The gate material selected was from the Kleber-Coulomb company: neoprene with nylon in two plys, which possessed outstanding physical properties, resistance to external stresses and chemicals. The latter was very important, for the river was not free of industrial wastes dumped into its upper reaches.

The shell has a thickness of 4.5 millimeters, overall length of 46.3 meters, expanded width of 7 meters, inflated height of 1.5 meters, mechanical strength of 8 t/m, and weight of 1.4 tonnes.

The gate shell was fabricated from 1.2- by 7-meter sheets bonded together in a lap seam on the long side with the aid of self-curing adhesives until the large 46.3- by 7-meter panel was obtained. The product was delivered to the construction site as a large roll 7-meters long and 0.6 meter in diameter on a wooden spool.

Installation of the gate consists in unrolling the panel and fastening it onto U-shaped metal members.

The shell was filled with two deep-well pumps that deliver 300 m^3/h through a common pipe; the pumps are situated in concrete suction pipes 0.6 meter in diameter located on the left bank above the inlet pier. The pumps are started up by a float mechanism that controls the headwater level. When that level begins to drop below the normal operating level, the pumps are switched on and the shell is filled; when the level begins to rise above that normal level, the pumps are switched off.

At the same time, other floats that also regulate the headwater level control a mechanical system for opening two butterfly valves; these valves release water from the shell into the tailwater when the headwater level begins to rise above the normal, and then shut off that flow in the reverse situation. The deflation rate depends on the degree to which the level has risen above normal.

It is not difficult to see that through the use of the floats to start up and shut off the filling pumps and the floats to control the butterfly valves, reliable and precise operation of the unit is ensured, and that due to the flexibility of the entire system, operation presents no difficulties.

In 1962, two dams with nylon water-filled gates were constructed in the U.S.A. The first of them was constructed on the Turtle Creek Canal for controlling the water level in the reservoir of the circulation cooling system for the city of Pittsburgh's thermal powerplant (operated by Westinghouse Electric Corp.).

In the previous 25 years, the city had suffered from two floods that had inflicted damage measured in millions of dollars. When flooding threatens (the flexible gate can be retracted within 2 hours at the most), the usual stream discharge of 2.5 m^3/s increases rapidly, consequently increasing the discharge into the adjacent Monongahela River which

runs together with the Allegheny at Pittsburgh to form the Ohio River. The time for retracting the gate shell usually is most adequate, because approximately 4 hours before the high water arrives, early warning signals are received from points upstream.

On the other hand, in the event of a rapid rise in the water level, more rapid automatic deflation of the gate is effected. If a cloudburst happens, the excess water is dumped right over the crest.

The totally inflated shell can maintain the water level at the 2.4-meter mark. Five hours usually are needed to fill the shell; water is supplied through a pipe passing through the canal wall. However, if necessary, the shell can be filled within 15 to 20 minutes through a special large hose.

The gate shell, which weighs 2858 kilograms and is 28.9-meters long, is secured to the concrete apron with stainless steel bolts, and on the ends to concrete piers on both canal berms. Its service life is 15 years (guaranteed by Firestone Tire & Rubber Company).

The second gate, of similar design and made of nylon-neoprene material, was installed in California on the San Joaquin River. It spans 50 meters with a head of 3.65 meters.

In 1963-64, two gates were constructed in Czechoslovak SSR according to a design developed by the Hydroproekt Institute in Brno. The first gate was installed on the Jevišovka River in 1963 and made in the form of a trapezium 7-meters wide along the bottom and 0.4-meter wide along the crest. The shell was made of FH-804 fabric manufactured by the plant "Tekhnolen" in Lomnice.

A second gate on the Jevišovka River near Žeročiče was installed in 1964 and has a rectangular width of 6 meters and height of 0.80 meter. The shell is filled by a hydraulic ram which constantly feeds water into a chamber connected by pipe to the void in the gate shell. The pumped-in water replenishes losses due to leaks or slight tears in the shell. The advantages of the hydraulic ram are its simple design and operation without an auxiliary energy source, which on a branched irrigation system is of importance.

It should be noted that the shell was torn in several places while being transported. As it was being installed, these places were not noticed. But despite this, the gate maintained the design head, thanks to the filling system.

The following results were obtained during tests of the second gate under winter conditions:

- The water in the dam chamber froze several days following formation of the ice sheet in the headwater.
- The water in the chamber froze from bottom to top in all cases; in the conical parts along the edges of the shell, it also froze very rapidly.
- If overflow was permitted, the water in the chamber did not freeze completely.
- In the spring, the ice in the gate chamber thawed earlier than in the river, which evidently is explained by the absorption of great amounts of solar radiation by its dark surface.

A third gate constructed in Czechoslovakia is the flexible gate of a raft chute on the Vltava River at Klecany. Initially, the raft chute with needle gate, situated on the right bank, was equipped with wooden sluice gates attached to the girder of a sliding steel foot bridge. The chute, 12-meters wide having a cascade bottom, was in bad shape. The wooden gates at the end of the chute were damaged and partly missing. From 1968 to 1970, the system was overhauled at a cost of 765,000 Czechoslovakian korunas.

The construction of an auxiliary flexible inflatable gate made it possible to avoid manual labor, accelerate the passage of water, and improve operation of the raft chute as a whole, especially during minor and nighttime repairs.

The gate shell is filled with water from the headwater through an opening 150 millimeters in diameter within 30 minutes, using a submerged pump located in a metal jacket fastened with anchor bolts to the left splitter pier. The rectangular shape of the shell is very convenient from the standpoint of manufacture.

The Rubena Nahod firm manufactured and installed the flexible gate for 23,900 Czechoslovakian korunas in less than 2 months.

During summer and winter tests, the gate was inflated with air. These tests showed that the

adopted shape was reliable. Signs of damage were not found.

The flexible gate has been in operation since the end of 1970. The experience of operating it has demonstrated that at the fastening points on the ends, there is slight damage, evidently caused by passage of suspended particles in the water through the resulting creases. It is recommended that these places be reinforced by bonding on an extra layer of rubber.

In 1966, in the state of Texas near Bay City on the Colorado River, a flexible gate was installed having a span of 70 meters and head of 4 meters for irrigation of rice paddies. The gate shell is filled to a height of 1.8 meters with water, and the remainder is inflated with air.

When the water level in the river rises, air is automatically released from under the shell, and the gate begins to operate with an overflow. When the water level in the river has dropped sufficiently, pumps automatically fill the shell with air, thus raising the gate and providing the necessary retaining height.

During floods, the gate is completely emptied and stored on the apron. The system for filling and emptying the gate is closely linked with warning and command systems that duplicate a manual control system.

Signals from sensors of headwater and tailwater levels, pressure within the gate shell, etc., are transmitted to a central control panel where they are received by relays that switch the pumps on and off and actuate the systems for filling and emptying the shell according to the required control program. Thus, the control of the gate can be completely automated.

In Holland, for partial regulation of velocities in canals and closing off individual reaches in the event the earth dikes are damaged, several composite-type flexible gates were designed and constructed up to 1969. The first of them, in North Holland, is 12-meters long and 2.10-meters high; the second, on the Weespertrekwaart navigation canal near Amsterdam, is 29-meters long and 3.7-meters high; the third, also near Amsterdam, is 29-meters long and 3.6-meters high; and the fourth gate, near the town of Lisse, is 26.5-meters long and 3.10-meters high.

The flexible composite gate consists of two flat steel doors attached to a metal trough-shaped floor with a waterproof hinge arrangement. A rubberized fabric is clamped around the edges of the doors. The trough-shaped floor, together with the steel doors and flexible shell, form a hollow chamber which is filled with water by electric pumps mounted in the abutments (fig. 8).

To eliminate the backwater, it is sufficient to release the water from the shell, after which it drops and hangs between the doors. The hollow doors, being filled with air, remain in operating position. After the air has been removed from them, they are lowered onto the apron. In this position, the doors protect the soft shell from damage. The cost of such a gate 29-meters long is 700,000 florins. A gate for similar purposes in traditional form, for instance, with sector gates, would cost much more.

In 1969, the first flexible gate was constructed in the GDR (German Democratic Republic) on the Mulde-Penig River (fig. 9): the width of the spillway opening is 46 meters, the highest head above the sill is 1.1 meters, and the normal is 0.85 meter. The hydrogeological conditions of operation of the spillway are determined by a normal discharge of 30 m^3/s at a headwater velocity of 0.1 m/s. The discharge of the river over the year averages 4 to 120 m^3/s, with the maximum observed being 240 m^3/s. It has withstood ice pressures from 5 tonne per lineal meter of gate (for ice thickness of 50 cm and length of field 50 m, moving at a rate of 0.2 m/s) up to 15 tonne per lineal meter.

The gate shell is inflated with air and has supporting and protective shells fastened to its crest. Such a gate (made of chloroprene rubber on a textile base) is distinguished by flexibility, and the ability to yield under unexpected and short-term loads, and its material is distinguished by high resistance to air pressure in the 85- and 95-centimeter H_2O range. The pressure is monitored every 14 days and air is added if necessary. When river discharge increases, care is taken so that the internal pressure does not increase above 300-centimeter H_2O.

In the section where the shell is attached to the apron, special attention is given to the reliability of the anchor bolts, spaced rather closely together, and to the rigidity of the longitudinal clamping element (made of a No. 30 channel bar) used for the

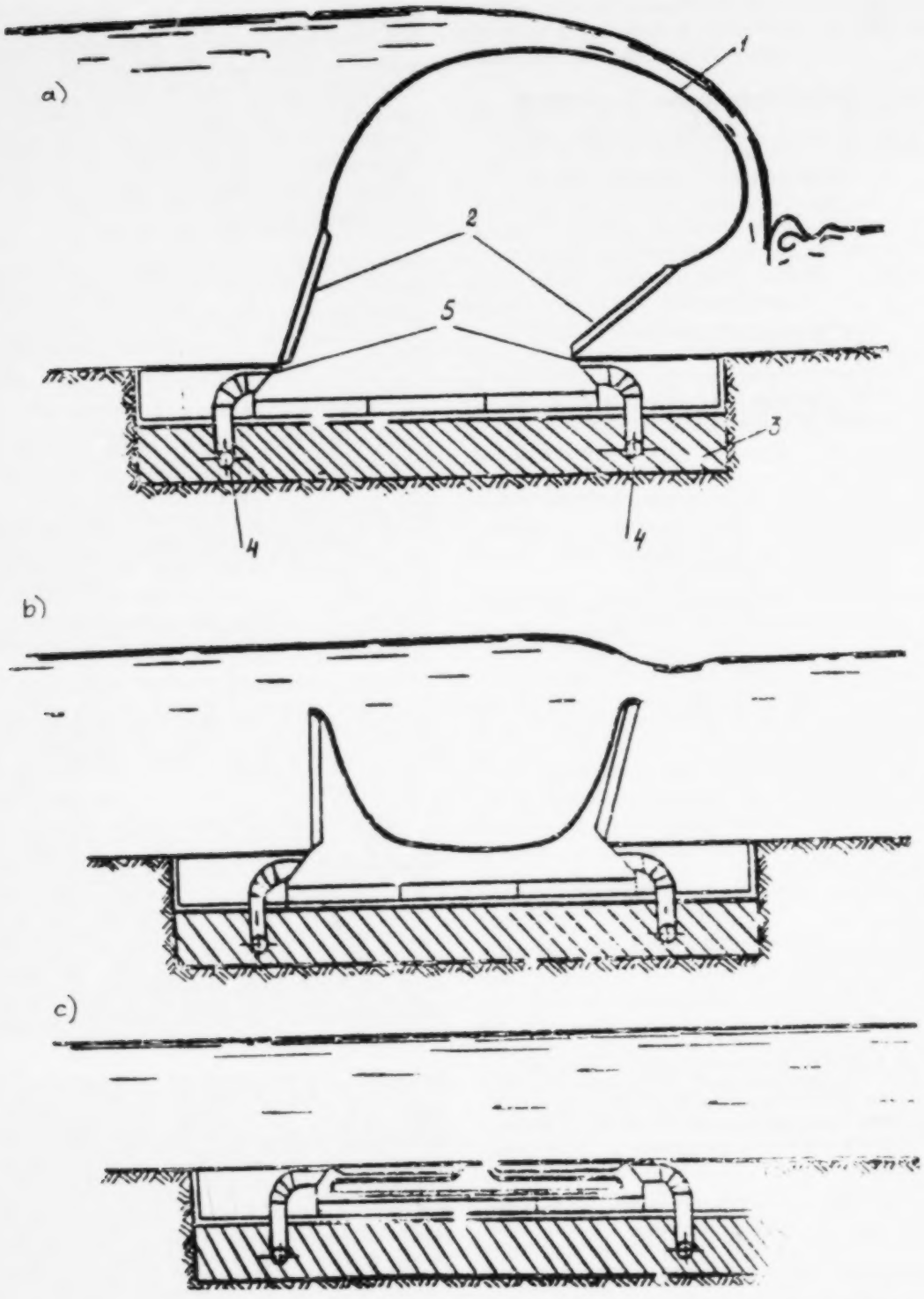

Figure 8. – Flexible composite gate (Holland): a) in design position, b) intermediate position, c) collapsed position. 1) shell, 2) steel doors, 3) concrete apron, 4) pipes for filling and emptying with water, 5) waterproof hinge assembly.

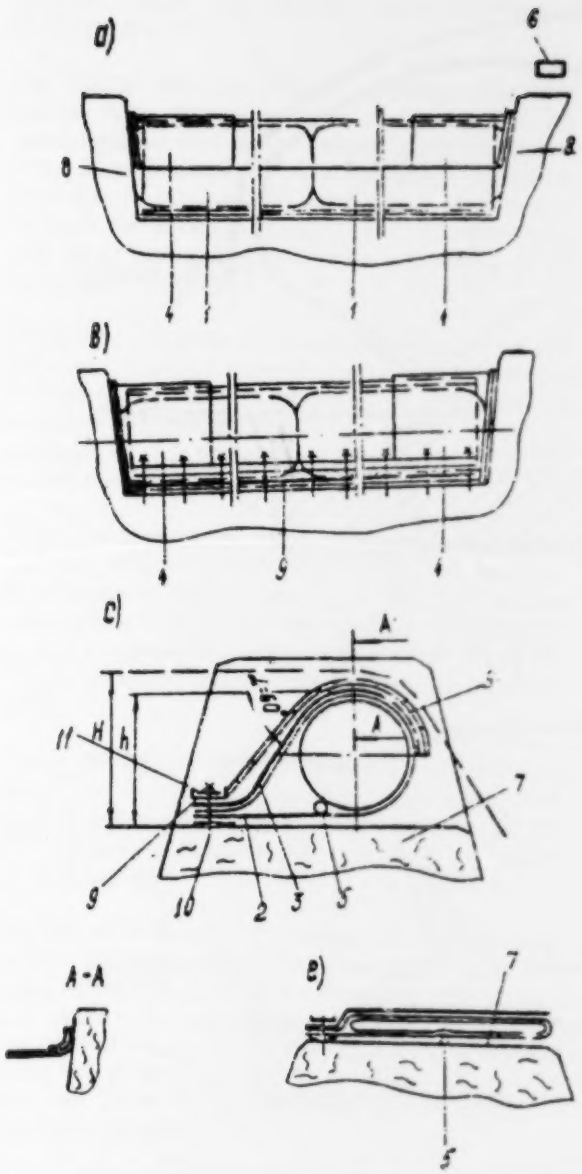

Figure 9. – Flexible gate on Mulde-Penig River (GDR). 1) insert, 2) supporting shell, 3) protective shell, 4) transition shell, 5) flexible hoses, 6) service point, 7) foundation, 8) abutments, 9) channel bars, 10) fastening bolts, 11) clamping plates.

purpose of applying constant pressure to force the shell against the sill along its entire length.

The protective shell, placed over the gate shell, is secured in the same assembly as the supporting shell. It is two ply: polyamide mesh coated with a top layer of rubber and is especially wear resistant. The same thick fabric as in the protective shell is used in the abutment couplings. When the gate is completely raised, the coupling elements must cover its ends for a length $>1.2\ D$ (D = gate diameter). Over the entire range of gate heights, the fabric of the coupling—owing to its elasticity—adheres to the remaining elements of the gate, thus sealing its ends.

The gate sections are supplied air by a compressor pumping 40 m^3/h at 0.3 atmospheric pressure (the design pressure inside the gate shell is 0.078 kg/cm^2) through a distributor along individual air hoses with valves that can be shut off independently.

During operation, air gauge pressure of 85- to 95-centimeter H_2O is maintained in the gate segments. The pressure is checked every 14 days and, if necessary, air is added. When the discharge in the stream increases, care is taken that the internal pressure in the gate shell does not rise above 300-centimeter H_2O due to its deformation. Operating experience has shown that the air-filled gate remains completely reliable even when iced over.

The economic effectiveness of using the air-filled gate was determined during reconstruction of the spoked dam installed in 1897. The cost of restoring the dam in its original form was determined to be 400,000 GDR marks, including 300,000 marks for construction and assembly. The actual cost of rehabilitating the air-filled gate was 67,000 marks, including 10,000 marks for construction and assembly. Thus, savings of 333,000 and 290,000 marks, respectively, were achieved. By virtue of the small volume, the construction and assembly work was completed in much shorter times (only 200 staff-hours) than would have been needed for construction in the traditional manner.

In 1970, on the Susquehanna River in Pennsylvania (U.S.A.), construction was completed on a seven-span flexible dam with total length of 800 meters and height of 2.3 meters. The length of the spans: six of 91.44 meters each and one of 53.44 meters. Piers are reinforced concrete, 3-meters high, 1.35-meters wide at the top, 2.7-meters wide at the bottom, and 6- and 9.6-meters long, respectively. The apron is reinforced concrete 6-meters wide, it has upstream and downstream cutoffs, and is connected through its top plate to the

piers. The abutments are as follows: on the east bank—160-meters long in the form of a rockfill dam with a reinforced concrete core 24-centimeters thick at the top and 40-centimeters at the bottom, resting on a reinforced concrete base 1.5-meters wide, and the downstream slope is paved; on the west bank—20-meters long in the form of a concrete gravity dam with an upstream cutoff. All the concrete structures are anchored into the foundation with metal bars 28 millimeters in diameter sunk to a depth of 1.8 meters. The spans between the piers are covered by flexible inflatable shells, 1.08-meters high when filled with water and 1.22-meters high when inflated with air. Water is diverted from the intake into the headwater through a conduit 300 millimeters in diameter, and then is fed to electric pumps through another conduit 100 millimeters in diameter. Filling and emptying can be effected either manually or automatically. Automatic emptying also is triggered by a rise in the normal operating level. The pumping unit, 400-millimeter discharge conduit, air compressor unit, and control panel are all located on the west bank.

Inflatable structures in the form of large diameter shells are being used in hydrotechnical construction to elevate the crests of dams and dikes, for paving training and deflecting groins, and flood control structures, and in the form of rolling weirs in which the shell retaining the head is secured to an apron.

The experience gained from operating such inflatable dams (gates) in a number of countries has demonstrated their operational advantages, which include the possibility of using them in rather dry climates and on rivers with severe hydrological regimes (unstable discharges, large volumes of sediment). Design, construction, and operation have revealed the expedient arrangements and design forms of this type of dam.

It has turned out that, for dams with low head, the shell should be attached by one generatrix to the apron, and for dams with high head, by the two generatrices. Into the inner cavity of the shell, air is fed under pressure or water is pumped at a head exceeding by several decimeters the backwater level being created. Here, the height of the shell in the raised position should not be more than 75 to 80 percent greater than its diameter.

To protect the shell from wear due to rubbing against the sill, to which the shell is attached when deflated, it is recommended that the concrete surface behind the shell and between the base end buttresses be coated with sheet rubber.

The material for a shell usually is rubber, neoprene, or similar materials reinforced with nylon fabric (single or multiply). Contrary to customary opinion, it is recommended that the material be thin (total thickness only several mm), which decreases the danger of its being damaged when deflated. In the U.S.A., thick material similar to automobile tire casings is used solely for dams deflated during operation only in very rare instances.

In designing and constructing inflatable structures, special attention must be given to the shell fastening assembly: the end of the base is wrapped around a steel border with rounded ribs; from above, another border is applied and the entire structure is fastened to the sill with bolts. In the case of combined fastening of the base ends along a single generatrix, a good result is obtained by first bonding the ends together.

Shells filled with water are more stable, less subject to vibration, and if the seal is broken, they empty slowly. However, deposits can form on the inside of such shells due to settling of suspended matter in the water. There also is the danger of water freezing inside the shell of the dam (gate) operating in an area with a severe climate. So, when the shell is being filled with water, it is recommended that separate systems be used for filling and emptying the shell, which makes it possible to flush out the cavity and prevent its freezing by feeding in warm water. Separate systems also serve as backups for each other.

It is recommended that the shell be connected to abutments of either the vertical or inclined type in the form of a triangle so that the vertex of the triangle is positioned in such a way that no wrinkles are formed on the end of the sheath. A small-scale model helps in determining the best form of connection. A successfully chosen side slope makes it possible to avoid completely the formation of creases on the shell ends. Depending on operating conditions, elimination of creases is preferable either when the shell is filled or when emptied; the latter usually applies on streams with a heavy sediment regime, when the high water sediments are forced upward over the shell lying on the apron.

If, during the extension of a dam, a shell can be placed over the entire length as a single section,

since its disassembly for repair is not coupled with great difficulties, then for run-of-the-river dams it is expedient to divide the shell into two or more sections to facilitate and lower the cost of dismantling and repair operations. In the latter instance, the shell sections are equipped with separate filling and emptying systems, and along the given sill piers with inclined faces are installed. The piers, submerged by the high water, have practically no effect on the passage of large discharges. To allow for modification and repair of the shells in the drained space, temporary barriers are installed on the upstream and downstream sills, and the support beams for those barriers are fastened in recesses.

Construction of inflatable structures is simple and is accomplished in a short time. For instance, a low head dam of this type on the Rhone River in Switzerland (fig. 10) was completed in just 6 weeks, and the total time from letting the contract for design and construction until the water began to rise upstream was 6 months. The dam was built in two phases, with concreting of the sill onto a tie beam in a trench to a height of 1.5 meters (of its total height of 2 m). The remaining part was concreted in following installation of the inserts and placing of piping for the filling system (consisting of two sections as well); the framing for this 0.5-meter layer of concrete was the channel piers. The supply of warm water into the shell from the cooling system of a nearby thermal powerplant was provided for winter operation. The filling and emptying system is automated on the basis of the headwater level (float gauge reading); when the normal water level is surpassed, the filling of the shell is decreased right down to its being forced against the sill by the flow.

The experience of operating this dam for 2 years has shown that blocks of ice up to 20 meters long have safely passed over the crest and that during high water, millions of cubic meters of sediment (bed load of alpine gravel and pebbles) have also passed without harm. Inspections of the shell have revealed no traces of wear. The shell is made of nylon fabric coated in the inside with rubber and on the outside with neoprene. The overall thickness of the material is 4 millimeters. The shell is bolted onto the embedded steel band in the sill; the end of the base is wrapped three times around another steel band which is then pressed down on the first band, causing the shell to fit tightly against the sill. The shell has not been noted to freeze

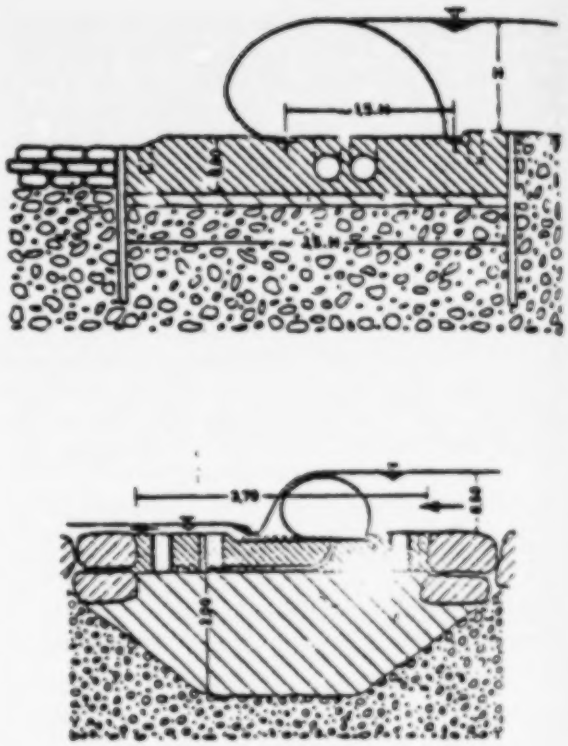

Figure 10. – Flexible dam on the Rhône River (Switzerland).

over, and winter operation has proceeded without incident, both emptying for passage of large discharges and filling to raise the headwater level.

In the Federal Republic of Germany (West Germany), flexible structures are used as repair gates on navigation locks. Structures in the form of water-filled cushioning (stilling) tanks are used as cofferdams on canals while they are being cleaned.

Worthy of attention and approval is the plan to preserve Venice with the aid of water-filled shells restrained in the flow from two sides by piles and cables. The design was proposed by A. Calamussi and V. Merli. The protection idea mainly consists in placing flexible gates at the mouths of the Lido, Malamocco, and Chioggia canals, covering spans of 548, 471, and 904 meters, respectively, and having heights of 8, 19, and 15 meters, respectively.

The water in Venice poses the main threat to its existence, due to: submergence of land, rising of

the Mediterranean Sea, reduced hydraulic resistance, and deterioration of the contact between the sea and lagoon (hydrobiological equilibrium). The construction time is 2 years, and cost is 30 billion lira, which is less by a factor of 10 than the cost of a variation involving traditional structures.

The expedience and technical feasibility of accomplishing such a feat has been demonstrated by the experience of constructing and operating an experimental gate having a span of 62 meters and height of 5 meters on one of the Venetian canals since November of 1974.

Construction of flexible structures is being carried out in other nations of the world as well.

For instance, inflatable gates having spans of 10 to 70 meters and heights up to 3 meters have been most widely used in Japan. More than 220 inflatable gates were constructed and used successfully for irrigation purposes in Japan from 1969 to 1975.

In Czechoslovakia, several tens of inflatable structures are in use for river training.

Several tens of inflatable gates have also been installed in the U.S.A., and more than 70 (including three in Gonkonde)[a] have been planned for construction. One of those projects in the Tulsa project in Oklahoma, where the Tulsa Metropolitan Area Planning Commission proposes to build four "Fabridam" dams on the Arkansas River in Tulsa. Each of the dams will have a span of 137.3 meters and height of 2.14 to 2.75 meters. The purpose of the project is to create reservoirs in recreation areas. The 2 highest dams will be placed about 8 kilometers from the city and will form a whole series of reservoirs that will blend in well with the natural landscape.

The cost of constructing a four-section "Fabridam" dam for an overall length of 550 meters for the Tulsa region will be 2 million U.S. dollars, while a conventional concrete dam of the same length with steel gates would cost $30 to $40 million.

Despite the fact that, in theory, there are no limitations on flexible dams as regards length, from the standpoint of economics as well as portability and convenience of all operations during installation, it is suggested that similar elements be no longer than 120 to 150 meters. If it is necessary to design a dam with longer span, then concrete piers must be constructed between the individual sections. In this case, the presence of a separate control system for each section increases the flexibility of the entire monitoring and control system. If, for some reason, concrete piers are unacceptable, the dam sections can be joined at their ends and controlled as a single large shell.

Pneumatic (inflatable) forms have recently begun to be used in a number of foreign countries in the construction of pipelines, canals, drainage systems, etc., rather than cast-in-place concrete.

At the site of one powerplant in the GDR, inflatable forms were used to produce concrete pipelines 200-meters long (two-section) of 120-centimeters diameter and 500-meters long (single section) of 180-centimeters diameter. Also, reinforced concrete pipes 40-meters long with inner diameter of 120 centimeters were produced. The wall thickness of the concrete pipes was 40 to 50 centimeters, and that of the reinforced concrete pipes was 20 centimeters.

The pipelines were constructed in the following manner. A trench with the desired section was dug. Along both sides of the trench were placed metal and wood stacking pallets which served as the outer forms for the pipes and kept the walls from caving in. Then the bottom of the trench was leveled and the base of the pipeline was concreted in. The base was given the shape of a trough. The preparatory grading ensured proper alignment of the inflated forms.

The height of the guide pallet was one-fourth the pipe diameter if it did not exceed 120 centimeters. When the diameter of the pipe was increased to 180 centimeters, the height of the pallet was equal to one-third its diameter.

The form shell was inflated with an air compressor to the design pressure and placed on the bottom of the guide pallet.

The pipe concrete was poured in sections. The effective length of a concreting section for one form was 9.5 meters. The hermetic seal and design pressure of the inflated shell were monitored as the placing continued.

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[a]Location is unclear in translation.

The upper part of the formwork was covered with a layer of concrete up to 20 centimeters which then was leveled and finished.

Attention was paid to the distribution of the concrete ingredients. The fines engaged immediately with the shell walls. This provided the pipe with a smooth inner surface and shielded the shell material from mechanical damage. Further finishing of the interior walls was not needed if the concrete was compacted well.

Preparatory work was done on the next section as the previous one was being concreted. When the concrete work was finished, the pressure in the form was reduced. After 12 to 15 hours, the diameter of the shell had decreased and it could be freely extracted from the pipe. Then the pneumatic formwork was moved on to the next section.

Pneumatic shells are now being manufactured for pipes up to 240 centimeters in diameter. If the shells are taken care of, they can be reused up to 80 times. They are stored dry and filled with a small amount of air. It is especially effective to use pneumatic forms when constructing pipelines in areas with complex topography, e.g., in the mountains.

Specialists in the GDR state that 96 hours are needed to construct a pipe 9.5-meters long using penumatic forms, whereas it would take 142.5 hours for the same length using traditional methods; i.e., construction time was reduced by 33 percent. The plan is to create an assortment of forms satisfying the needs of the pipe construction industry.

In Italy, pneumatic forms are used widely to construct drainage pipes and gutters in tunnels and at airports. One Italian firm has manufactured pneumatic forms 25-meters long and 60 centimeters in diameter. It was used 500 times to lay 10 kilometers of pipe.

In Holland, polyamide bags measuring 1.3- by 2.2-meters with a capacity of 0.75 m^3 and put into position by a floating crane are used to close up washout gaps (they can be reused after recovery). The weight of nylon bags with sand is as much as 5 metric tons. The strength of the bags is considerably reduced (by 50%) in those spots on the structure that are periodically under water or generally are not submerged.

Synthetic coatings are used to protect banks, bottoms of conveyance structures, and the seacoast from erosion.

Blankets that can be submerged to the bottom are made from 16.5- by 70-meter two-ply nylon panels weighted down by sand placed in special pockets arranged so as to distribute 15 kg/m^2 (of blanket area). The blankets are wound onto a system of rollers mounted on a carriage lowered to the bottom; as the carriage moves along the bottom, the blanket is unwound from the rollers, and the carriage passes over it, pressing it firmly against the bottom.

Polyethylene film blankets 0.1- to 0.15-millimeter thick on a wire mesh up to 18- by 75-meters in size are submerged in running water at flow velocities up to 0.5 to 1.0 m/s using cobbles and crushed rock.

DOMESTIC EXPERIENCE IN DESIGN, CONSTRUCTION, AND OPERATION OF FLEXIBLE STRUCTURES

Here, hydrotechnical construction does not have a great deal of experience upon which to base its use of flexible structures, but Soviet research engineers were coming up with original ideas regarding flexible structures as far back as the 1940s. For instance, membrane structures (canvas gates) were the subject of a number of investigations carried out in the 1940s at the All-Union Sci. Res. Inst. for Water Supply, Sewer Systems, Hydrotechnical Structures and Engineering Hydrogeology (VNIIVodgeo) by Prof. N.P. Rozanov, E.S. Kuznetsov, Cherkasov, and others. A number of proposals were put into practice during the advance of Soviet forces during the Great Patriotic War (WW II). In particular, a structure was made of sheet piling and canvas that made it possible within only a few hours to flood territory occupied by the enemy, thereby immobilizing their motorized forces (developed by Prof. S.G. Gutman). Firehoses, already in use for many decades, lightweight diversion structures, cofferdams in canals — all these structures could only be used for a brief period, due to their lack of strength and the rotting of material, and only now with intensive growth in the production of synthetic resins, rubbers, and fibers has it become really feasible to create a great variety of hydrotechnical structures using synthetic materials.

This report presents a survey of research carried out under the leadership of Dr. Tech. Sci. B.I. Sergeev at the Novocherkassk Reclamation Engineering Institute and at the Southern Sci. Res. Inst. for Hydraulic Engineering and Reclamation by co-workers, currently Cand. Tech. Sci. I.A. Petrov, G.A. Shtokalov, V.L. Bondarenko, Iu.M. Kosichenko, N.E. Kalashnikov, V.A. Volosukhin, and V.N. Shchedrin, engineer A.D. Popov, and a great number of engineers with other industrial, design, and affiliated organizations: A.G. Guiumdzhibashian (Iuzhgiprovodkhoz), V.I. Karpenko (Ukrgiprovodkhoz), Iu.B. Bogush (Ukrgidroproekt), A.Kh. Iakupov (Kuban'giprovodkhoz), B.N. Tkachenko, and N.N. Dobrianskiy (Khersonskiy SKhI), E.P. Bychkov (Tatgiprosel'khozstroi), V.M. Kotovskiy (Lower Don Region Hydrotechnical Structures Administration), and others.

This group's scientific and industrial links with production, research, design, water management, and other organizations in many cities of the Union are assisting in the successful solution of many complex problems concerning the development and application of flexible structures. Inestimable aid in the matter of coordinating and implementing these operations has been provided by the Northern Caucasus Higher Learning Science Center, directed by Corresponding Members of the U.S.S.R. Academy of Sciences Iu. A. Zhdanov and I.I. Vorovich, and the Hydraulic Engineering and Reclamation division of VASKhNIL (All-Union Order-of-Lenin Academy of Agricultural Sciences im. V.I. Lenin), directed by Corres. Member of VASKhNIL B.B. Shumakov.

This report contains a brief survey of work carried out by co-workers at TsNIILesosplav, Giprogor, and Gidrorybproekt, who are working in conjuction with the Novocherkassk group.

Flexible Dam on the Shchuchka River

An attempt to construct an experimental water-filled dam was undertaken by the staff at Giprolestrans (Leningrad) under the management of engineer K.I. Strakhov in 1963 on the Shchuchka River in Kingisepp region of Leningrad oblast.

The flexible dam consisted of a water-filled shell and apron, made of canvas and coated with bituminous mastic to make it waterproof; it was then covered with a layer of paper so the sun's rays would not melt the mastic. The dam was around 5-meters long and 0.5-meter high.

The shell of the dam was filled with water by a pump. Due to lack of experience in building such structures, the apron was not anchored and weighted down, and no energy dissipator was provided downstream, so the dam managed to stand for several hours, mainly because it was operating with an overflow.

Despite the operation of that flexible dam for only a few hours, it demonstrated the feasibility of constructing flexible dams with flexible aprons that not only function as seepage-control structures, but provide structural stability as well.

Flexible Dam on the Kiterno River

Considering the great promise of using flexible dams for temporary impoundments of small rivers, co-workers of the Hydraulic Structures Department of the Novosibirsk Institute for Water Transportation Engineers (NIIVT) under the leadership of the author (on the instructions of the Tiumen' Oblast Agricultural Administration in 1966) designed, manufactured, and installed the first flexible dam in the U.S.S.R. for water management purposes on the Kiterno River.

This flexible dam consisted of a flexible upstream blanket, shell, and downstream spillway apron, which offered erosion protection for the downstream channel. The flexible dam had the following main parameters; length 15 meters, width 16 meters, width of shell 14 meters, perimeter of shell 8.4 meters, capacity of shell 60 m^3, volume when collapsed 0.5 m^3, and weight 500 kilograms.

The dam was erected in the natural channel without additional grading of the bottom and sides. It was unfolded on the bank, then pulled into the streambed with a Belorus tractor behind fabric straps fastened every 3 meters along the entire perimeter of the dam, and attached to anchors.

After this, the shell was filled with water to a height of 1 meter and operated in that state. In winter, the water was pumped out of the shell. The spring runoff, with considerable icepack, passed over the dam without harming it.

The minor experience gained from operating the flexible dam under actual working conditions demonstrated the technical feasibility of using it under

overflow conditions. It brought out the necessity of solving a number of related problems, for instance, when filled too full, the shell pulled out the attachment assembly along with the upstream blanket, discharge openings were needed to empty the shell, etc.

Taking into account the previous drawbacks discovered during operation, in 1967, a new flexible dam project was developed and put into operation on the Kiterno River, with the dam manufactured at the Ufa Rubber Technical Products Plant.

In the second dam, as in the first, the same simple material pattern was used; the entire dam consisted of three types of triangular elements (upstream blanket, shell, and downstream spillway apron), which simplified the manufacturing technology to the maximum.

The dam had the following main parameters: length 19.2 meters, width 16 meters, width of shell 14 meters, perimeter of shell 8.4 meters, capacity of shell 60 m^3, volume when collapsed 0.8 m^3, weight 700 kilograms, and impounded head 2.5 meters.

The design also contained two openings in the form of hoses running along the edges for filling and emptying the shell.

In contrast to the first flexible dam, the second was situated on piled earth; it was as if a small earth retaining dam had been built, and then the flexible dam was erected on the top of that. The advantage of this design variation is that greater heads can be impounded with the same amount of construction material, and the entire installation process is carried out under dry conditions.

The second dam, in contrast to the first, was designed for operation in both summer and winter. The operating experience of 1967-68 demonstrated the possibility of using such structures year round. The water in the shell freezes immediately after the first frost and thaws before the ice drift begins, which gives time to empty the shell and allow the ice to flow over it. Damage to the shell has not been found as a result of either the freezing of water and expansion of ice inside it (the material is highly deformable) or the passage of high water. A small amount of scour discovered downstream from the spillway apron proved the necessity of extending that apron.

Flexible Dam on the Grushevka River

In 1969, under the direction of the author, a new flexible dam was constructed according to a design produced at the Novocherkassk Reclamation Engineering Institute (NIMI). In contrast to the previous structures, this one was made of different materials; the shell was fabric P-1 on Kapron (polycaprolactam fiber) 1548, and the upstream and downstreams aprons were fabric on Kapron 1539. To make assembly and dismantling easier, the dam was made of separate elements (upstream blanket, shell, and sectional spillway apron with a small auxiliary shell) which were joined directly at the construction site and could be replaced during operation in case of damage.

The dam was erected on the Grushevka River (in Rostov oblast) in the first year directly in the river channel on an earth dike, and in the second year, an earth dam was built across the channel and the flexible dam was placed on a side channel.

The construction experience in the first year revealed the difficulty of anchoring the dam when placing it in running water. The positive experience of erecting the dam in the second year was reinforced by the experience gained on the Belaia River in 1970.

Flexible Dam on the Belaia River

In the arid northern and eastern regions of Rostov oblast, local runoff is the sole source of water that can be used for irrigation.

Now, when collective and state farms are equipped with advanced technology, the use of local runoff is gaining in scope. Many farms located in arid regions are creating within their own territory small irrigated plots. With proper selection of the ways and means of using local runoff, all the investments will be paid back within 1 to 2 years.

The widespread development of small-scale irrigation will contribute to further growth and stabilization of agriculture. On existing, although small irrigated plots, collective and state farms will achieve high crop yields regardless of climate conditions.

In 1970, a new flexible dam was manufactured by the Ufa Rubber Plant according to an NIMI design

for the Zavety Lenina collective farm in Konstantinovskiy region of Rostov oblast. This dam was intended for operation as a spillway structure for a reservoir created on the Belaia River for irrigation of 300 hectares, and consists of individually constructed shells, upstream blanket, and sectional energy dissipator, all joined together with metal plates and bolts (figs. 11 and 12).

The flexible dam, functioning as a spillway structure designed to allow passage of high waters to within 1 percent of 92 m^3/s, is situated in the embankment of a 400-meter earth dam in the Belaia River channel, which has an upstream slope of 12:1, downstream slope of 2:1, height 7.0 meters, reservoir capacity 1400000 m^3, and effective storage 950000 m^3.

The flexible dam has the following dimensions: height 2 meters, width 24 meters, shell width 15 meters, shell perimeter 8.5 meters, length 25 meters, capacity of shell when filled 80 m^3, volume when folded up 1.5 m^3, and weight 900 kilograms.

The dam shell and energy dissipator were made from two-ply fabric on Kapron 1539 with tensile force of 8 t/m, and the upstream blanket and downstream apron were made of single-ply fabric on Kapron 1539.

The upstream blanket panel is placed on a 10:1 slope in the headwater, and its edge is turned under, buried 0.5-meter deep, and anchored. The blanket is weighted down by a layer of soil 30- to 80-centimeters thick. The upstream blanket panel, the downstream apron panel, and the shell of the dam are all joined into a single unit with steel plates and bolts. The shell of the energy dissipator is attached to the downstream apron in exactly the same manner.

The dam shell, together with the apron and blanket, is fastened along the length of their connection by individual push-pull rods 8 millimeters in diameter and spaced every 0.5 meter to wooden anchors 15 to 17 centimeters in diameter. The anchors are secured a distance of 2 meters into the headwater at a depth of 1 meter. The connection joint of the shell along the fastening line and at the ends is hermetically sealed by lining it with a strip of soft rubber 4-millimeters thick.

Transporting the dam from storage and installing it takes two shifts of eight persons on a team. Five years of experience in operating that structure has demonstrated the correctness of its design, its economic soundness, and its long-term promise.

The dam shell is folded up during floods. The function of transition is taken on by the downstream apron and the auxiliary earth-filled shell, which prevents scour downstream from the structure. The moment the flood is over, the dam shell is filled with water and remains in the design position until the reservoir level is drawn down to the height of the dam, at which time the shell is removed, inspected for damage, and then stored. In spring, before the runoff begins, it is reconnected to the upstream part. In the intervals between floods, the downstream apron is covered with a layer of dirt 15-to 20-centimeters deep so that it is protected from the sun's rays.

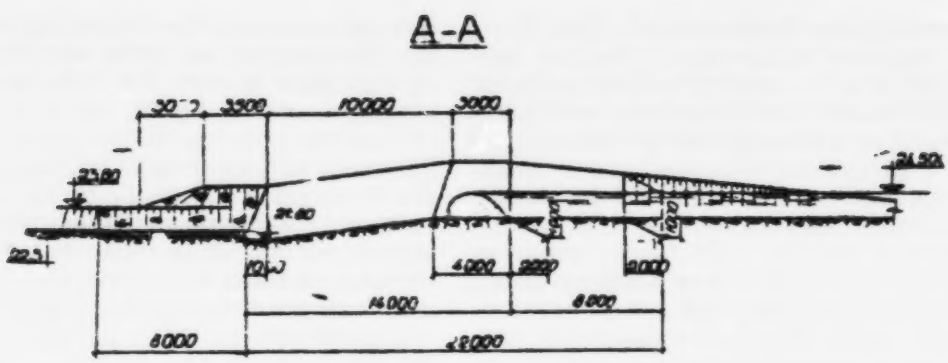
The dam might not even be put in use for several years because of low water levels. Its service life is about 8 to 10 years, dictated by the resistance of the material to various factors.

Flexible Gate on Canal R-2

In 1970, an immediate need arose to construct a temporary check structure on canal R-2 of the Mar'iano-Cheburgol' rice irrigation system during construction of the second stage of the same irrigation system (MChOS), in Krasnodar Krai (Territory).

The structure used was a flexible gate, which differed from a flexible dam in that the supporting shell was not attached to an upstream blanket (flexible apron), but rather to a concrete foundation. The gate was manufactured at the Ufa Rubber plant according to design from fabric No. 93 on Kapron 1539, and was a two-ply (one inside the other) shell attached along a single generatrix. The structure was characterized by the following dimensions: height 3 meters, width 22.4 meters, shell perimeter 12.84 meters, internal volume 160 m^3, volume when folded up 0.5 m^3, and weight 350 kilograms.

The flexible gate was installed near pumping plant NS-1 on an existing concrete lining of the bottom and berms of canal R-2 by a team of five in a single shift, having first made a concrete cutoff with anchor bolts buried every 0.5 meter. The



PLAN OF FLEXIBLE SPILLWAY

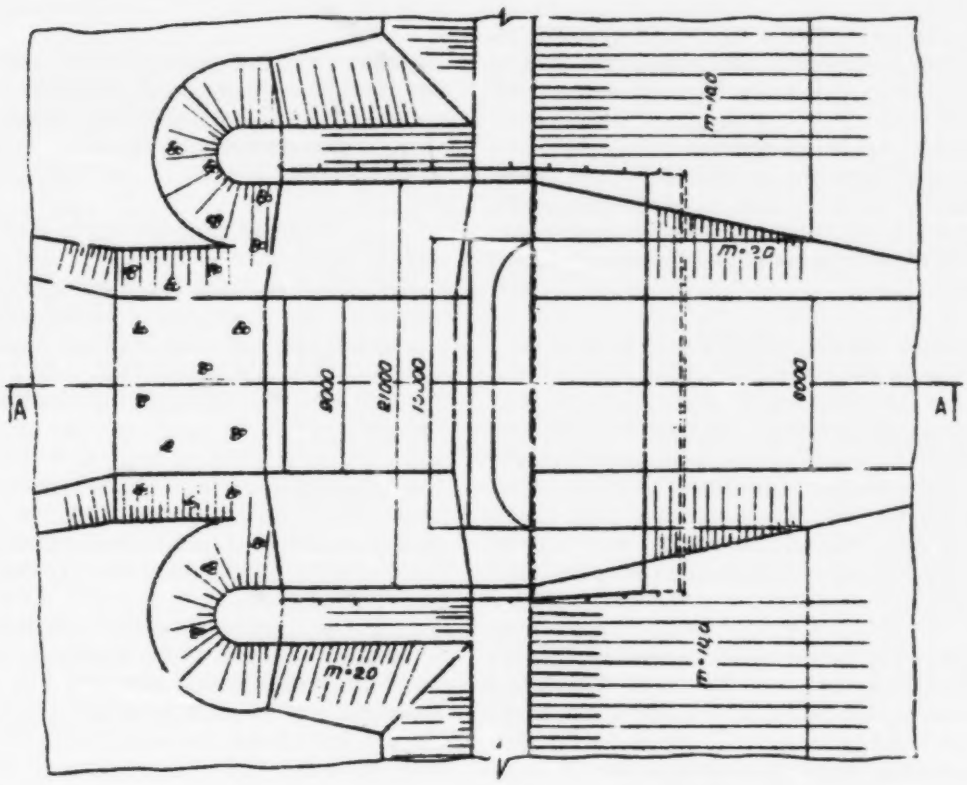


Figure 11. – Flexible dam on the Belaia River in Rostov oblast. Plan and cross-section.

openings in the fabric for the bolts were made at the construction site.

The gate shell was filled with water by an electric pump within 2 hours by means of a connecting pipe situated on the right side of the shell.

As a result of operation of this gate, important conclusions were drawn which proved very useful for subsequent structures. In particular, rhythmic vibrations in the shell were noted at discharges of 20 to 28 m^3/s, and they were accompanied by fluctuations in the headwater level (± 10 cm) and

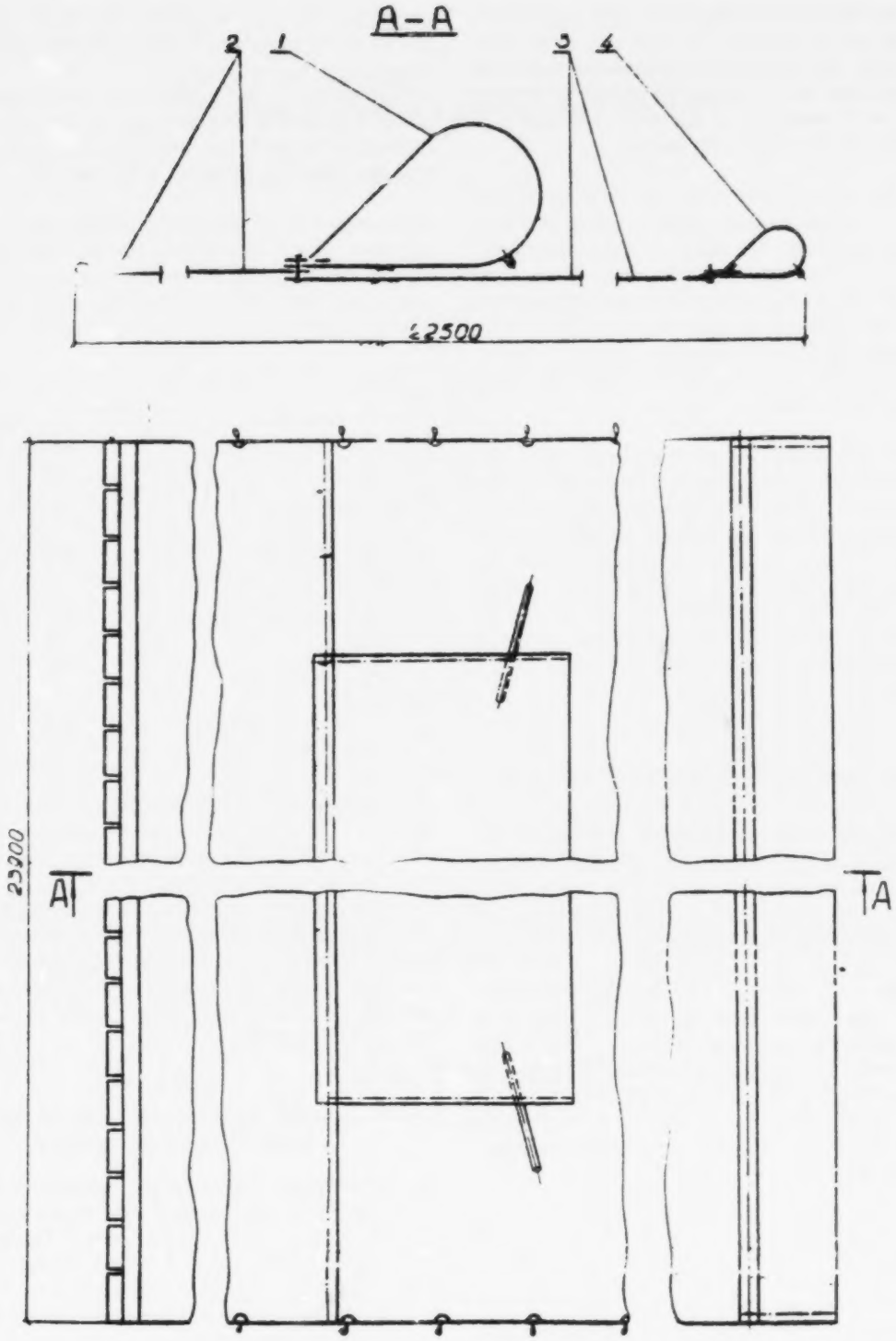


Figure 12. – Flexible dam on the Belaia River. Fabric pattern: 1) shell, 2) upstream blanket, 3) downstream apron, 4) flexible baffle wall.

a noise. Insufficient inflation of the shell, poor preparation of the foundation (it was not even reinforced), and the rythmic vibrations of the shell caused the seal to be lost at its points of attachment to the foundation. It became necessary to periodically fill the shell with water.

For the next year's operation, the shell perimeter was diminished by 2 meters and its lower part was filled with soil in bags and backfill. These measures in turn led to overloading of one of the shells, and then of the other, since the inner shell turned out to be 30 centimeters smaller than the outer. The safety factor of 3 to 4 obviously proved to be inadequate and so in subsequent structures, it was required to be 5 to 8.

A number of interesting phenomena were observed when the shell was inflated with air, for instance: the crest of the shell was uplifted on the same edge as where the air was supplied; distribution of air throughout the entire length of the gate at the nonregulated canal discharge of 15 to 25 m^3/s was difficult because the air tended to concentrate next to one edge (slope), causing greater stresses and deformation of the material in that place.

Flexible Gate on the Shaitan-Prorva Canal

In February 1973, the headworks of the Shaitan-Prorva Canal of the Talovskaia irrigation system was put in operation. It is an open distribution point consisting of a flexible gate on a concrete apron and a side offtake regulator (figs. 13, 14, and 15).

The design was developed at the Southern Sci. Res. Inst. for Water Management Construction with the author acting as consultant. The amount of water taken was regulated by two metal vertical lift gates located on the offtake regulator. A flexible gate, 31-meters long for a head of 1.74 meters, was installed to provide the necessary constant headwater level.

In terms of design, the gate is a water-filled exposed cylinder attached to a precast reinforced concrete apron along two generatrices. The transition at the banks is a side slope with 2H:1V. The flexible gate was manufactured at the Ufa Rubber plant from fabric No. 780 with strength along warp and weft of 10 t/m; the fabric was manufactured at the Iaroslavl Rubber Plant. Gate height is regulated by filling or emptying the shell, using two S-798 pumps located in the pumping plant.

When passing the maximum discharges (57.0 m^3/s), the shell is emptied and stored in a special recess in the apron. In this case, the gate is open and the dam operates as a full section.

All operations for regulating headwater levels and allowing flowthroughs are carried out automatically by maintaining the proper pressure inside the gate shell. The technical and economic indices of the structure are presented in table 1.

Table 1. – Flexible gate on the Shaitan-Prorva Canal.

Parameters	Units	Amount	
		Flexible gate	Regulator
Design discharge	m^3/s	57.0	22.0
Design head	m	1.74	1.74
Volume of gate shell	m^3	250.0	– –
Rating of pumping plant	kW	5.6	– –
Delivery of pumping plant	m^3/s	110.0	– –
Volume of reinforced concrete:	m^3	274	178
Precast	m^3	92	110
Cast-in-place	m^3	182	68
Equipment	tonne	0.26	1.0
Metalwork	tonne	3.0	7.0
Planned cost of construction and assembly	1000 rubles	106.0	– –

The headworks was constructed by "Kizliarrisvodstroi" trust of Glavdagestanvodstroi (Daghestan Central Administration for Water Management Construction). The design instructions for this structure called for the use of eight metal lift gates, each spanning 4 meters, to create the backwater on the Talovka River. The result from using a flexible gate in the working drawings was a yearly savings of 95,000 rubles with respect to construction and operation.

Flexible Gate on the Lock of the Novo-Manych Cofferdam

As a first-stage measure in the managed utilization of water resources between the western reach of Proletarskaia Reservoir and Manych-Gudilo Lake, pending completion of total reconstruction of the Novo-Manych cofferdam, construction of a temporary regulator in the embankment of the existing cofferdam is suggested.

The Novo-Manych cofferdam was constructed in 1932 as a temporary dike designed to isolate the

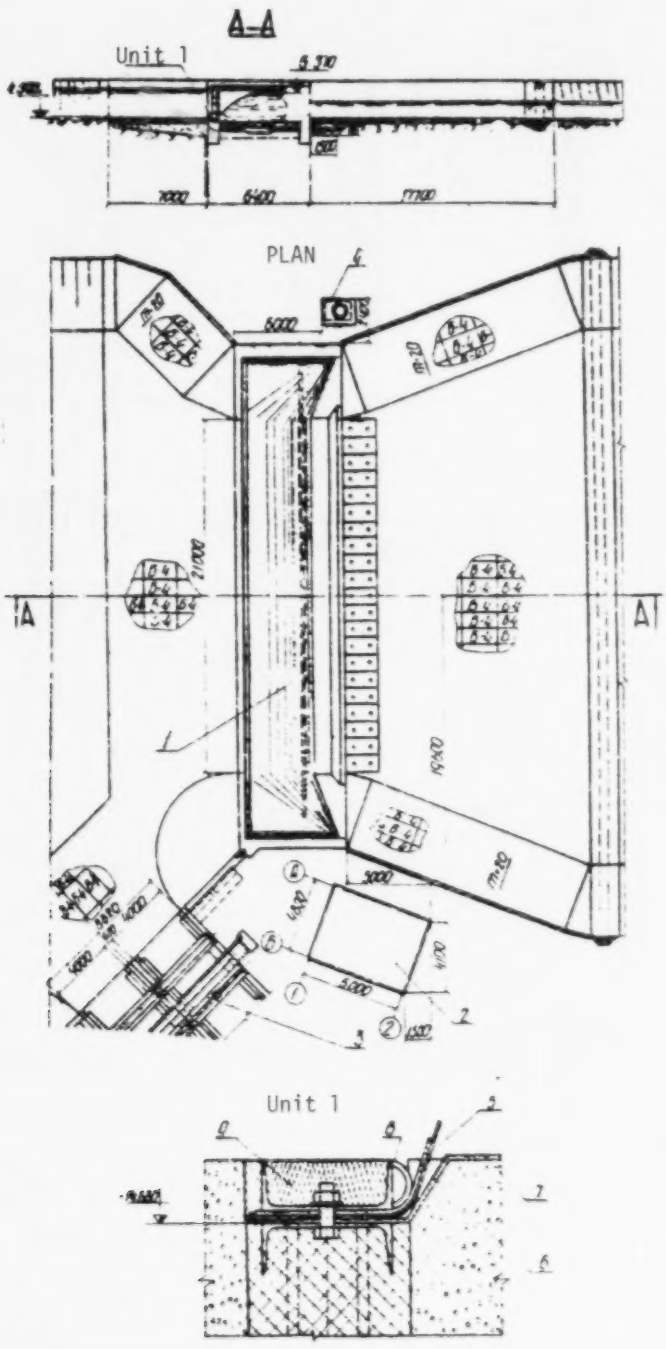


Figure 13. – Flexible gate on the Shaitan-Prorva Canal in Daghestan ASSR. Plan, section, and detail. 1) gate shell, 2) pumping plant, 3) offtake into canal, 4) emergency outlet from shell, 5) shell fabric, 6) rubber overlap, 7) rubber apron liner, 8) clamping channel bar, 9) bituminous mastic.

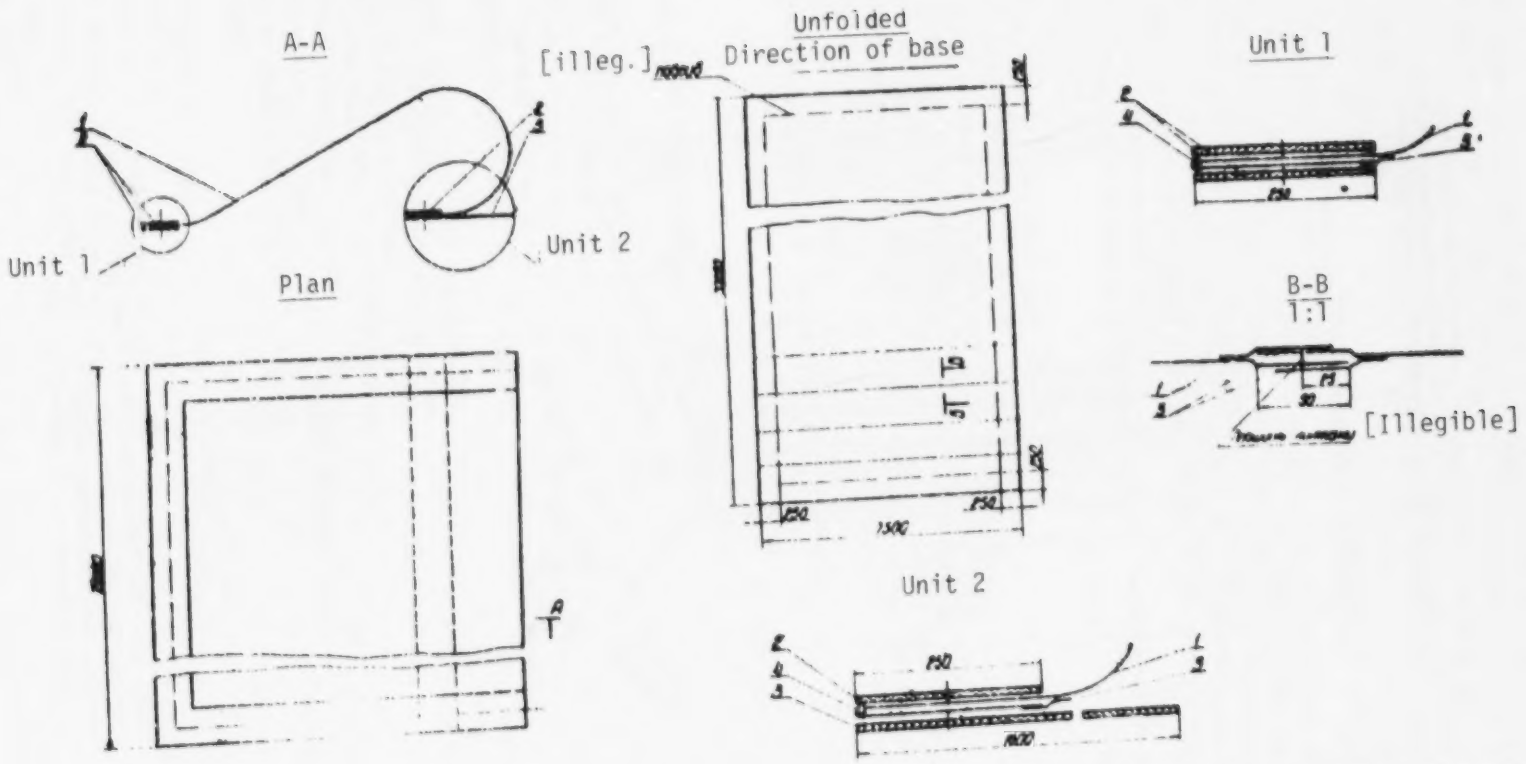


Figure 14. - Flexible gate on Shaitan-Prorva Canal. Pattern of shell fabric. 1) shell fabric, 2) rubber spacers, 3) fabric of apron lining, 4) Kapron flexible cable, 5) overlapping on seams.

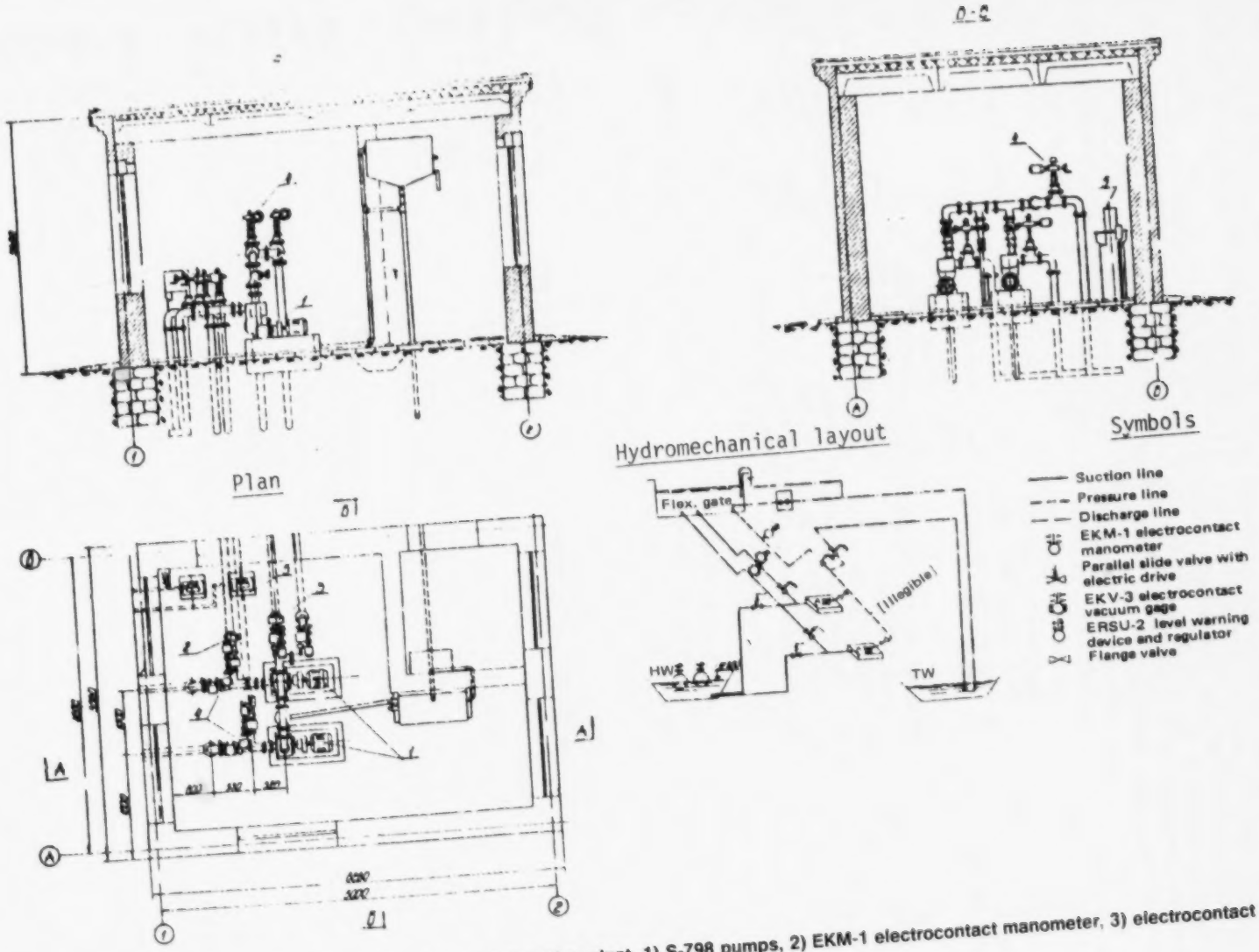


Figure 15. – Flexible gate on Shaitan-Prorva Canal. Pumping plant. 1) S-798 pumps, 2) EKM-1 electrocontact manometer, 3) electrocontact vacuum gauge, 4) slide valves with electric drives, 5) ERSU-2 level warning device.

work area of the Proletarskaia hydrotechnical complex and divert the flow of the Egorlyk River into Manych-Gudilo lake. At the completion of construction on the Proletarskaia hydrotechnical complex, the southern end of the Novo-Manych cofferdam, located at the mouth of the Egorlyk River, was arranged so that the discharge of this river was once again directed to the west, toward Veselyy Reservoir, previously constructed on the Manych River. Even since that time, the Novo-Manych cofferdam has been retained, functioning as a divider wall in Proletarskaia Reservoir, dividing it into two reaches — the freshwater west and mineralized east which are fed by the Manych-Gudilo salt lake.

The Southern Sci. Res. Inst. for Water Management Construction, with the author acting as consultant, designed the hydrotechnical structures for the Novo-Manych cofferdam. The unit is intended for temporary operation until completion of measurs for multiple-purpose utilization of the water resources of the Kuban' and Don River basins, for the purpose of regulating discharges between the western and eastern reaches of Proletarskaia Reservoir, two-way passage of fish through the structure, and passage of ships of the fishing and merchant fleets (figs. 16 and 17).

The structure is situated in an existing excavation on the northern side of the cofferdam and includes the following:

- Experimental hydrotechnical fish passage
- Navigation lock-regulator with flexible gate
- Pumping plant for filling and emptying the gate shell (water) and aiding in the operation of the jet pump for the fish passage

In the design sense, the structure is an open distribution regulator and all of its elements are made of cast-in-place reinforced concrete. The flexible gate of fabric No. 708 is installed in a concrete dock structure and fastened to the apron on four sides (through the two generatrices and at the corners along the bottom of the dock). Due to the absence of linkages to the walls, the gate can accept head from either side. The gate height is regulated by filling the shell with water and emptying it, using two 16-NDN pumps located in the pumping plant.

In the period when maximum discharges are being passed, the shell is emptied and stored on the apron. In that position, the gate operates in full section, opening a passage for fish and boats. The design parameters of the structure are presented in table 2.

The structure is being constructed by the Rostovdonvodstroi trust.

Table 2. – Flexible gate on the lock of the Novo-Manych cofferdam.

Parameters	Units	Amount	
		Regulator	Pumping Plant
Design discharge	m^3/s	30.0	– –
Design head	m	2.0	8.0
Volume of gate shell	m^3	300	– –
Rating of pumping plant	kW	– –	55.0
Delivery of pumping plant	m^3/s	– –	0.43
Volume of concrete:	m^3	581.0	244.0
Cast-in-place	m^3	518.0	233.0
Precast	m^3	63.0	21.0
Equipment	tonne	7.4	5.2
Metalwork	tonne	12.2	6.3
Planned cost of construction and assembly	1000 rubles	79.7	– –

Flexible Dam on Temernik River

The question of regulating the Temernik River at Rostov-on-Don arose as far back as the 1880s because the Rostov central (railroad) station is situated in the flood plain of this river, and on two occasions during rapid snowmelts accompanied by cloudbursts, the station tracks have been flooded. Also, in periods when the Temernik has been backed up by the Don, the Temernik has silted up severely and, just as a stagnant body of water, has become unsanitary.

A flexible dam placed at the mouth of the Temernik will permit the river to be backed up periodically, and then the water can be discharged into the Don. The structure was designed by the Southern Sci. Res. Inst. for Water Management Construction. It consists of a flexible dam and a submerged pumping plant (figs. 18 and 19).

The shell of the flexible water-filled dam is made of fabric No. 889 with tensile strength of 20 t/m. The fabric will be fastened to the existing concrete walls and apron along the two generatrices. Its length is 20 meters and height is 5.0 meters. The dam shell is filled and emptied by two pumps (8 KM – 18 a) in the pumping plant. The design parameters are presented in table 3.

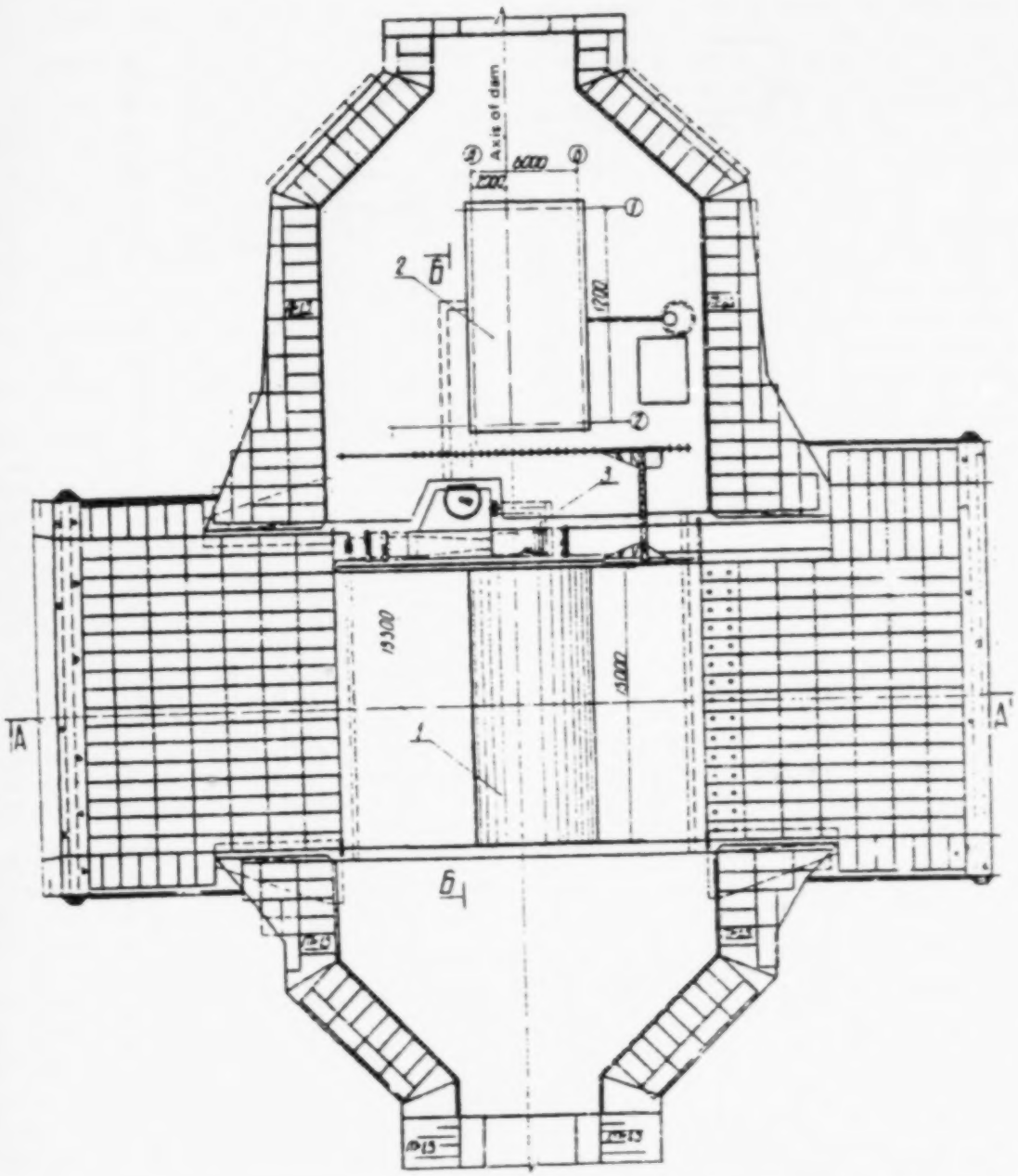


Figure 16. – Flexible gate on lock-regulator of Novo-Manych cofferdam. Plan. 1) shell, 2) pumping plant, 3) fish passage.

Dams on Malaia Kuberle and Mokryy Elanchik Rivers

The dams on the Malaia Kuberle and Mokryy Elanchik Rivers are designed to create reservoirs for the purpose of storing water for municipal uses.

In the design, the dam is a structure consisting of the following elements (fig. 20):

- Upstream blanket of kneaded clay loam
- Apron and stilling basin of cast-in-place reinforced concrete

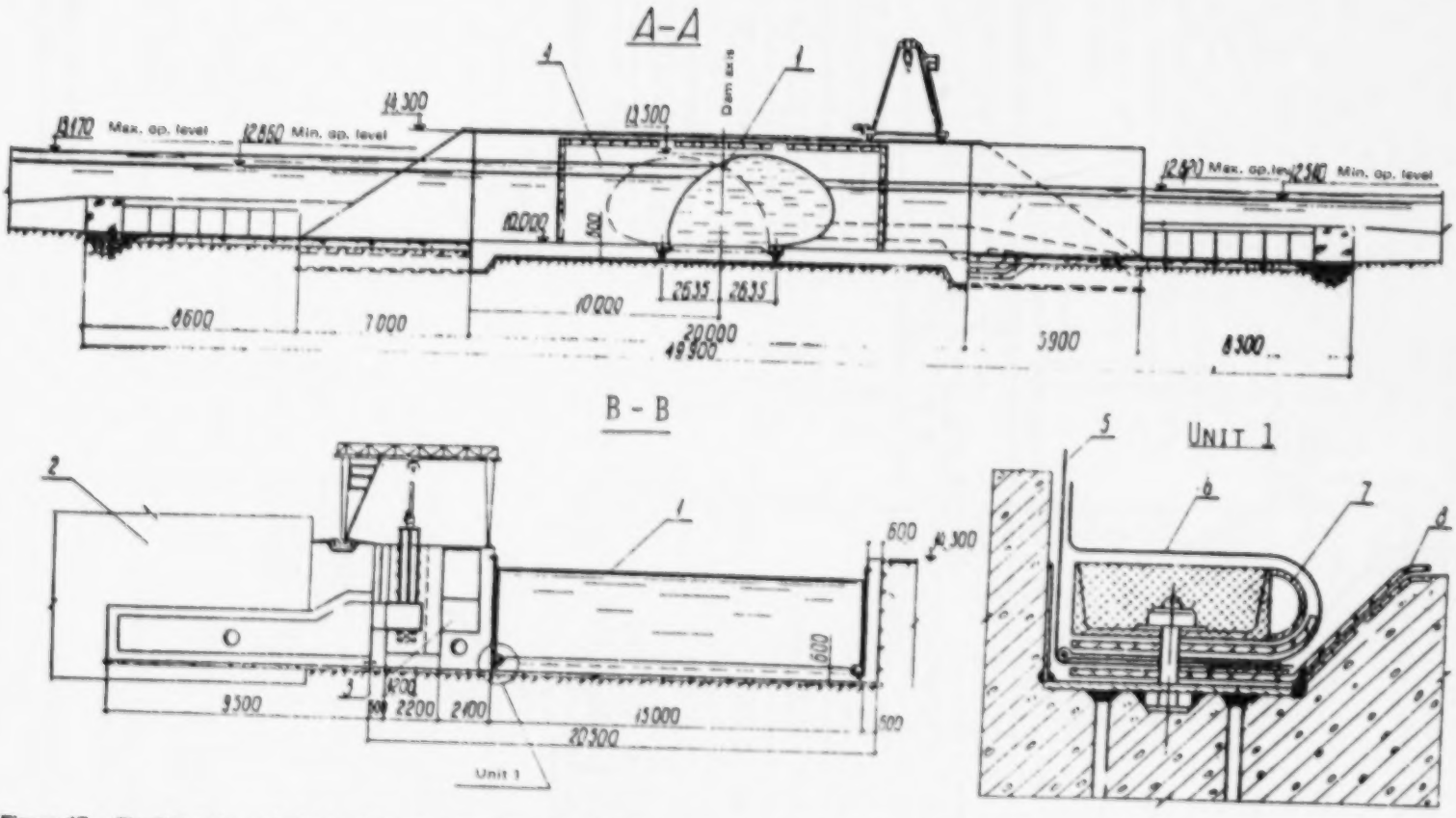


Figure 17. – Flexible gate on lock-regulator of Novo-Manych cofferdam. Cross-section and details. 1) shell, 2) pumping plant, 3) fish passage, 4, 5) fabric of side seal, 6) fabric of shell, 7) clamping channel bar, 8) rubber lining.

Table 3 – Flexible dam on Temernik River.

Parameters	Units	Amount
Maximum discharge	m^3/s	250.0
Design head	m	5.0
Volume of gate shell	m^3	700.0
Rating of pumping plant	kW	125.0
Volume of reinforced concrete:	m^3	124.0
For flexible gate	m^3	90
For pumping plant	m^3	34
Planned cost of construction and assembly	1000 rubles	58.0

- Downstream spillway apron of elastic Kapron fabric No. 1539
- Spillway part of dam of fabric No. 1548

The concrete slab of the apron and stilling basin is made of from BGT-100 concrete 100-millimeters thick with a waterproof coating. The energy dissipating part of the dam is a water-filled shell made of elastic Kapron fabric No. 1548 on a rubber backing placed on the main apron and side slabs. The height of the spillway part of the dam is regulated by filling the shell with water and emptying it with a pump located in the pumping plant. To allow passage of maximum discharges, the shell is emptied and collapsed onto the apron. In this position, the river channel functions as a full section. All operations for regulating the headwater level are automatic, based on maintaining the necessary design pressure inside the dam shell.

The configurations of both dams have been designed so that when they are flat against the spillway apron, the river sections will have their original shape and area (figs. 21 and 22).

The pumping plant is a submerged well having axial dimensions of 2.5- by 3.75- by 4.2-meters (fig. 23). The plant is equipped with a 6 KM-12 pumps, two DU-100-millimeter slide valves with electric drives, and two ERSU-2 level warning devices. One of the slide valves is mounted on the shell filling line, and the other on the outlet pipe.

The level warning devices are activated by the headwater and regulate the level in the pond. The pump delivery pipe is equipped with an ĖKM-1 manometer that limits the pressure inside the shell.

Dam operation is described as follows:

In winter, the dam shell is collapsed onto the apron and the river channel operates as a full section. Just before the spring runoff, the shell must be filled. Slide valve No. 2 is closed, slide valve No. 1 is opened, and the pump is switched on (manual control). When the normal operating level is reached in the headwater, the automatic control system is engaged and it provides subsequent regulation.

When the headwater level rises 30 centimeters above the normal operating level, slide valve No. 1 is closed, the pump is switched off, and slide valve No. 2 is opened, so that the shell is emptied and the water level drops. When the water level falls 30 centimeters below the normal operating level, slide valve No. 2 is closed, the pump is switched on, and slide valve No. 1 is opened. The shell fills and the headwater level begins to rise again. In this manner, the water level is varied within a 60-centimeter range, i.e., ± 30 centimeters from the normal operating level.

When the maximum dam height is reached, the ĖKM-1 electrocontact manometer keeps the shell from bursting due to excess pressure by switching off the pumps and closing the slide valves. In case of ĖKM-1 malfunction, provision is made for emergency discharge through a 300-millimeter pipe situated at the level of the design excess pressure inside the dam shell (fig. 24). The design parameters of the dam are presented in table 4.

Table 4. – Flexible dams on Malaia Kuberle and Mokryy Elanchik Rivers.

Parameters	Units	Amounts	
		Dam on Malaia Kuberle River	Dam on Mokryy Elanchik River
Design discharge	m^3/s	400.0	600
Head	m	2.6	2.6
Maximum height	m	2.8	2.8
Length of dam	m	53.0	58.0
Perimeter of shell	m	9.0	9.0
Volume of shell	m^3	340	550
Planned cost of construction and assembly	1000 rubles	45.0	47.0

Flexible Dam and Gate in Mius Bay, Rostov Oblast

The hydrotechnical complex in Mius Bay, after its completion, will perform the following functions (fig. 25):

- Accumulate freshwater from the Mius River to be used in irrigation

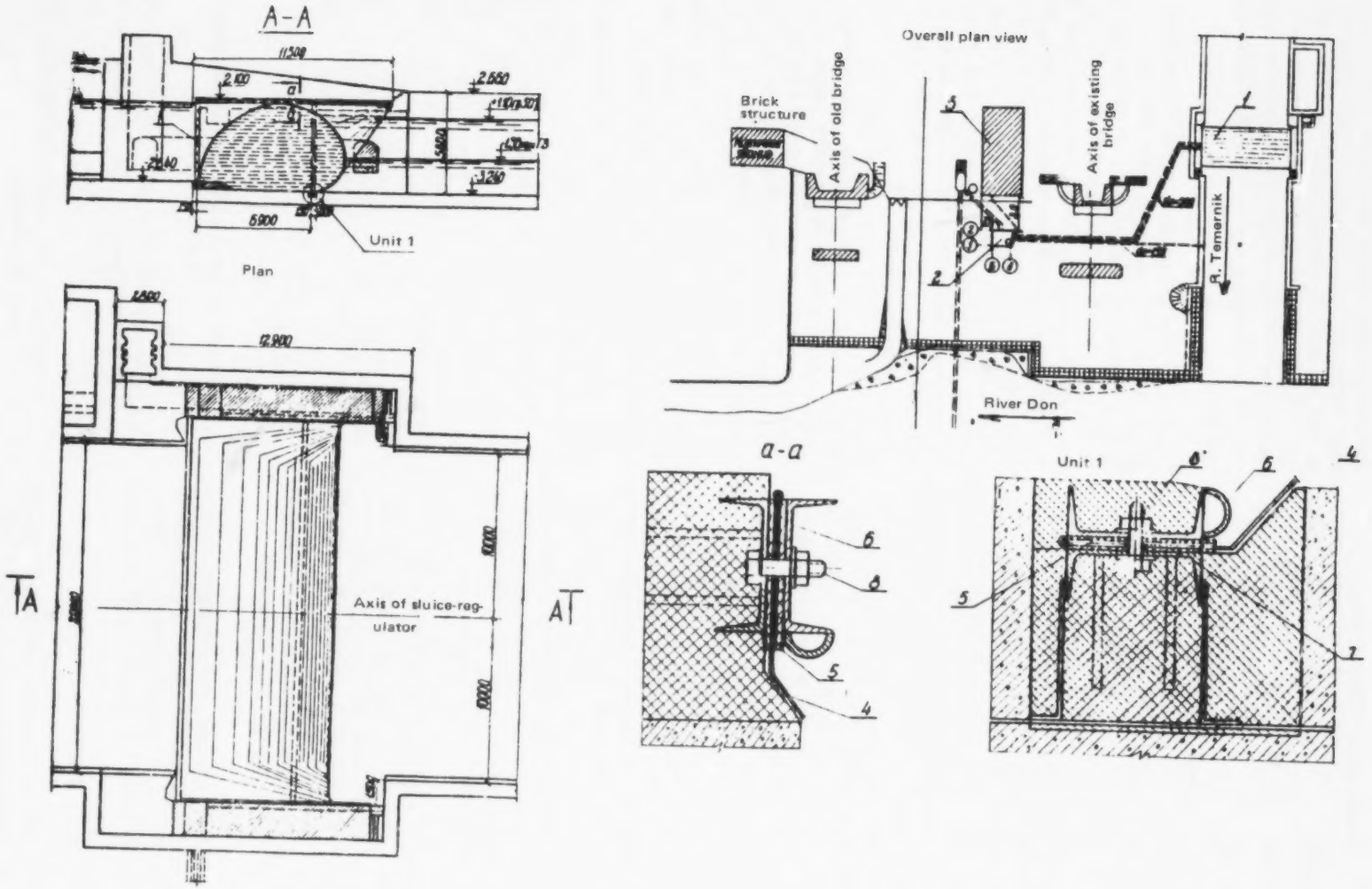


Figure 18. – Flexible dam on the Temernik River at Rostov-on-Don. Plan, cross-section, and details. 1) shell, 2) pumping plant, 3) existing water purification plant, 4) fabric of shell, 5) rubber insert, 6) clamping channel bar, 7) insert channel bar, 8) bolt with nut.

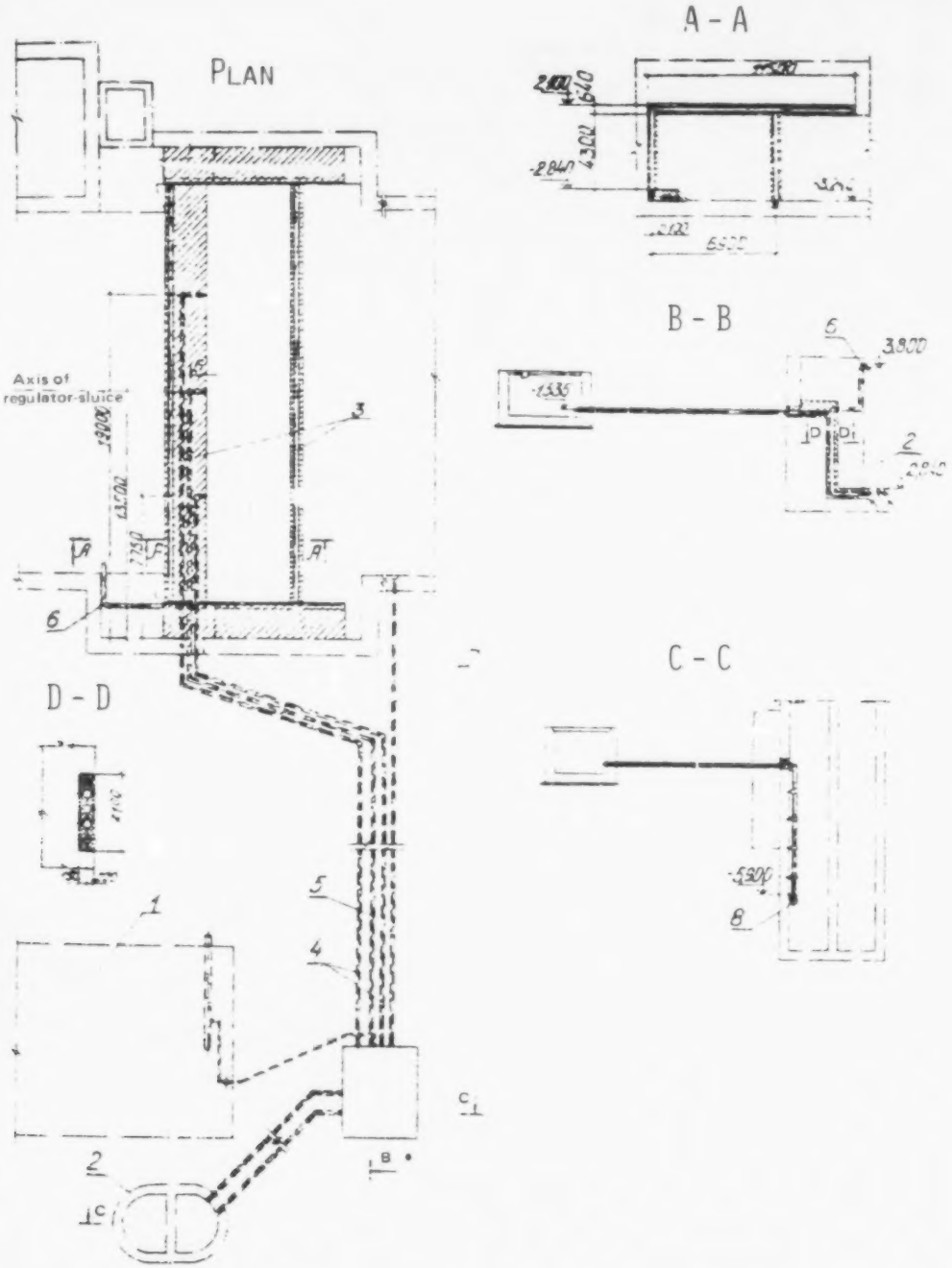


Figure 19. – Flexible dam on the Temernik River. Layout of pipelines and arrangement of inserts. 1) existing water purification plant, 2) water intake, 3) sunken fasteners for shell, 4) suction pipeline, 5) pressure pipe, 6) emergency water outlet for shell, 7) pipe for emptying shell, 8) no-return valve.

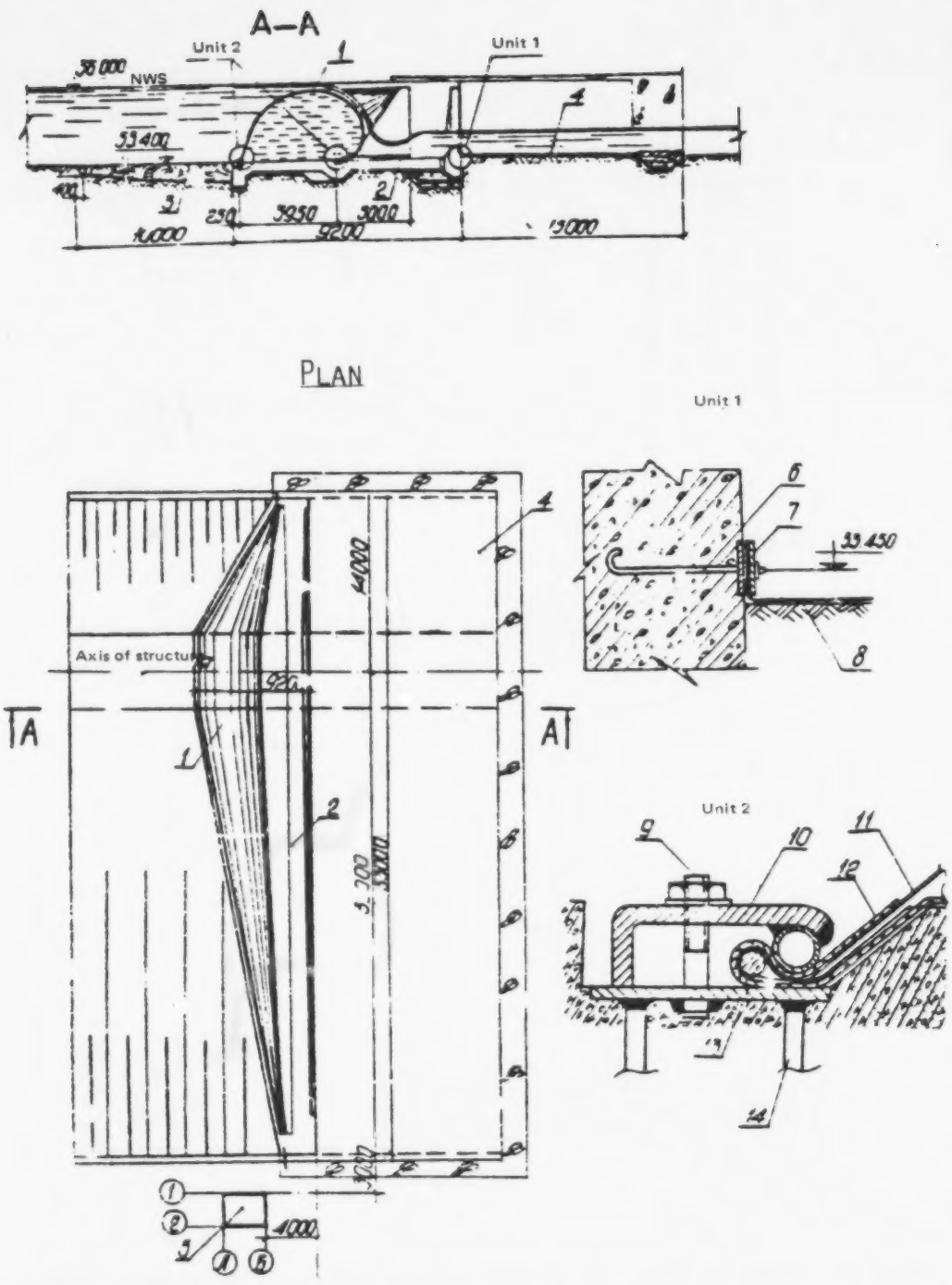


Figure 20. – Water-filled flexible dam on the Malaia Kuberle River in Rostov oblast. 1) shell, 2) apron, 3) upstream blanket, 4) flexible downstream apron, 5) pumping plant, 6) embedded anchor for fabric of downstream apron, 7) clamping strip, 8) fabric of downstream apron, 9, 10) clamping assembly, 11) fabric of shell, 12) rubber lining of apron, 13) insertion piece, 14) embedded part.

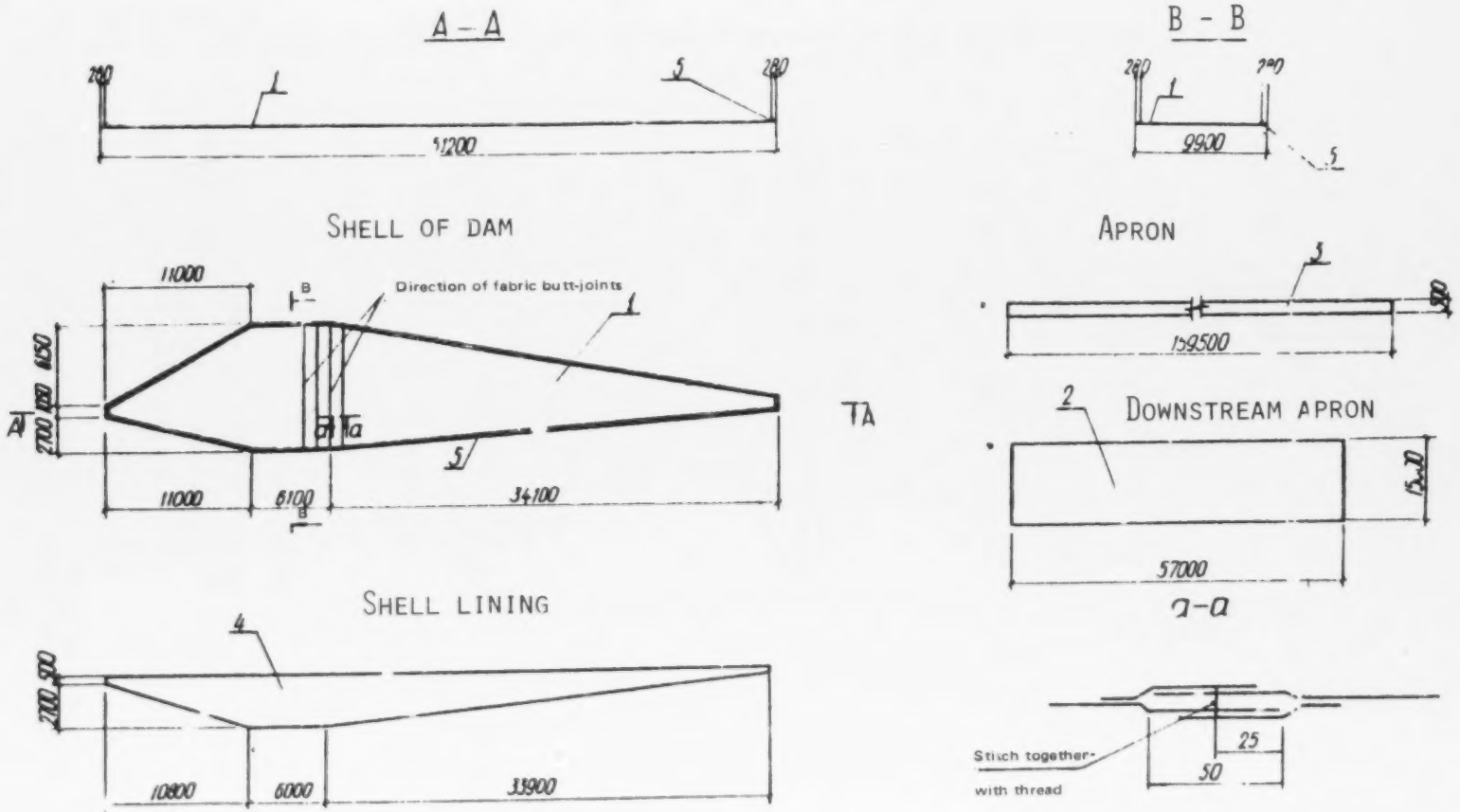


Figure 21. – Flexible dam on the Malaia Kuberle River. Patter of fabric. 1) shell, 2) flexible downstream spillway apron, 3) rubber lining, 4) rubber lining under shell on apron, 5) Kapron cable.

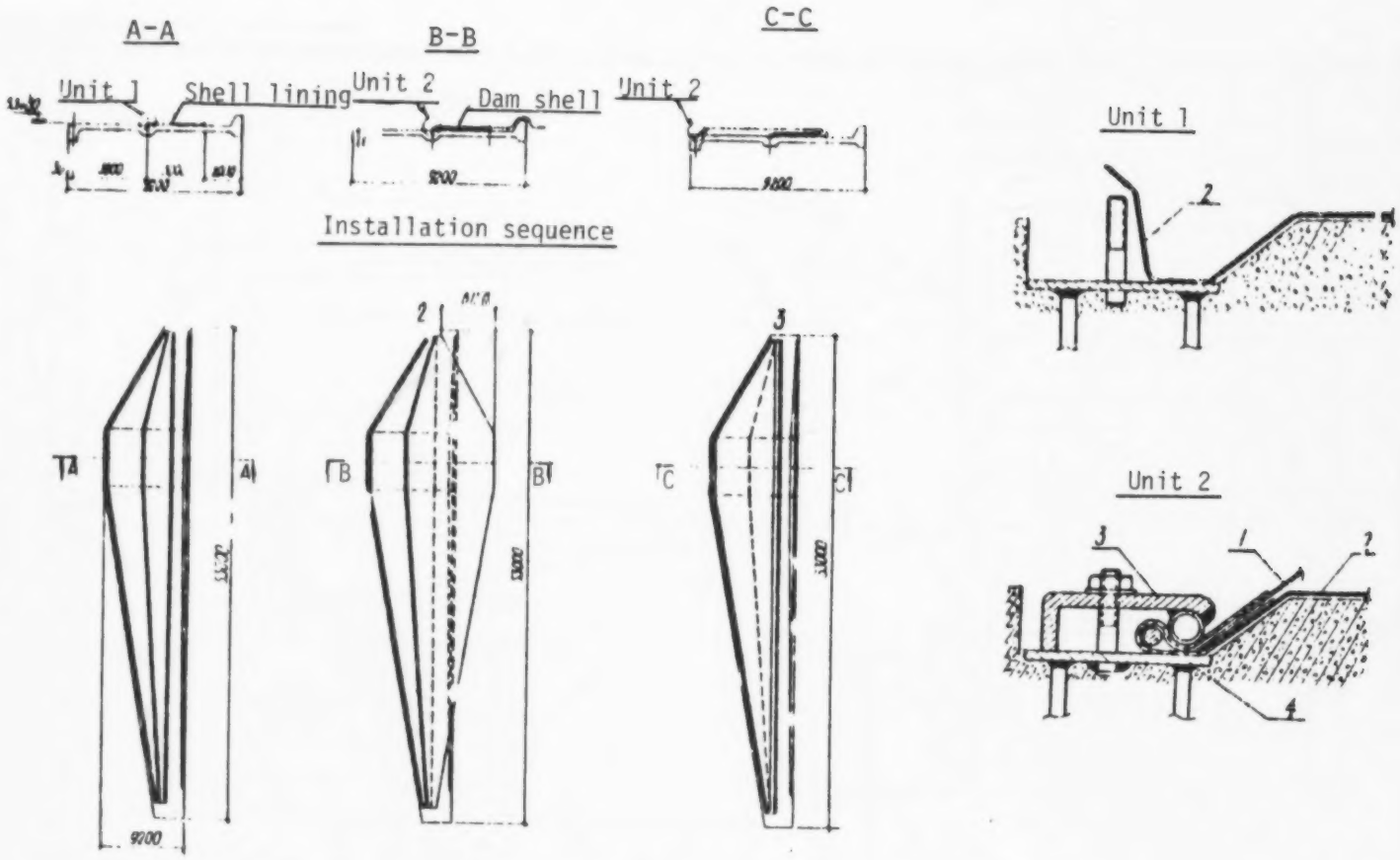


Figure 22. – Flexible dam on the Malaia Kuberle River. Adjustable configuration. 1) shell of dam, 2) shell lining, 3) clamping assembly, 4) embedded part.

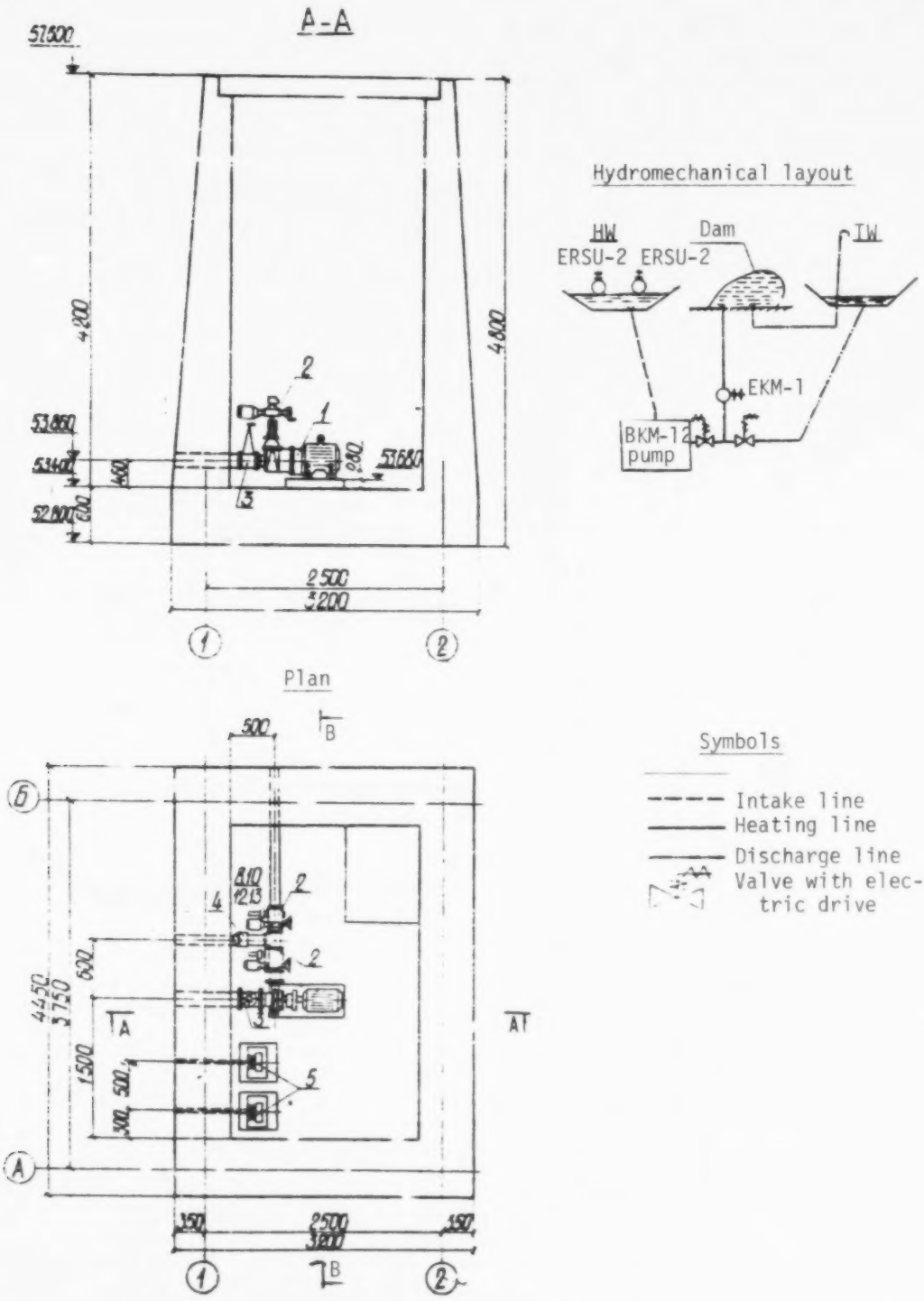


Figure 23. – Flexible dam on the Malaia Kuberle River. Pumping plant. 1) pump, 2) slide valve with electric drive, 3) manual valve, 4) electrocontact manometer ĖKM–1, 5) ĖRSU–5 level warning device.

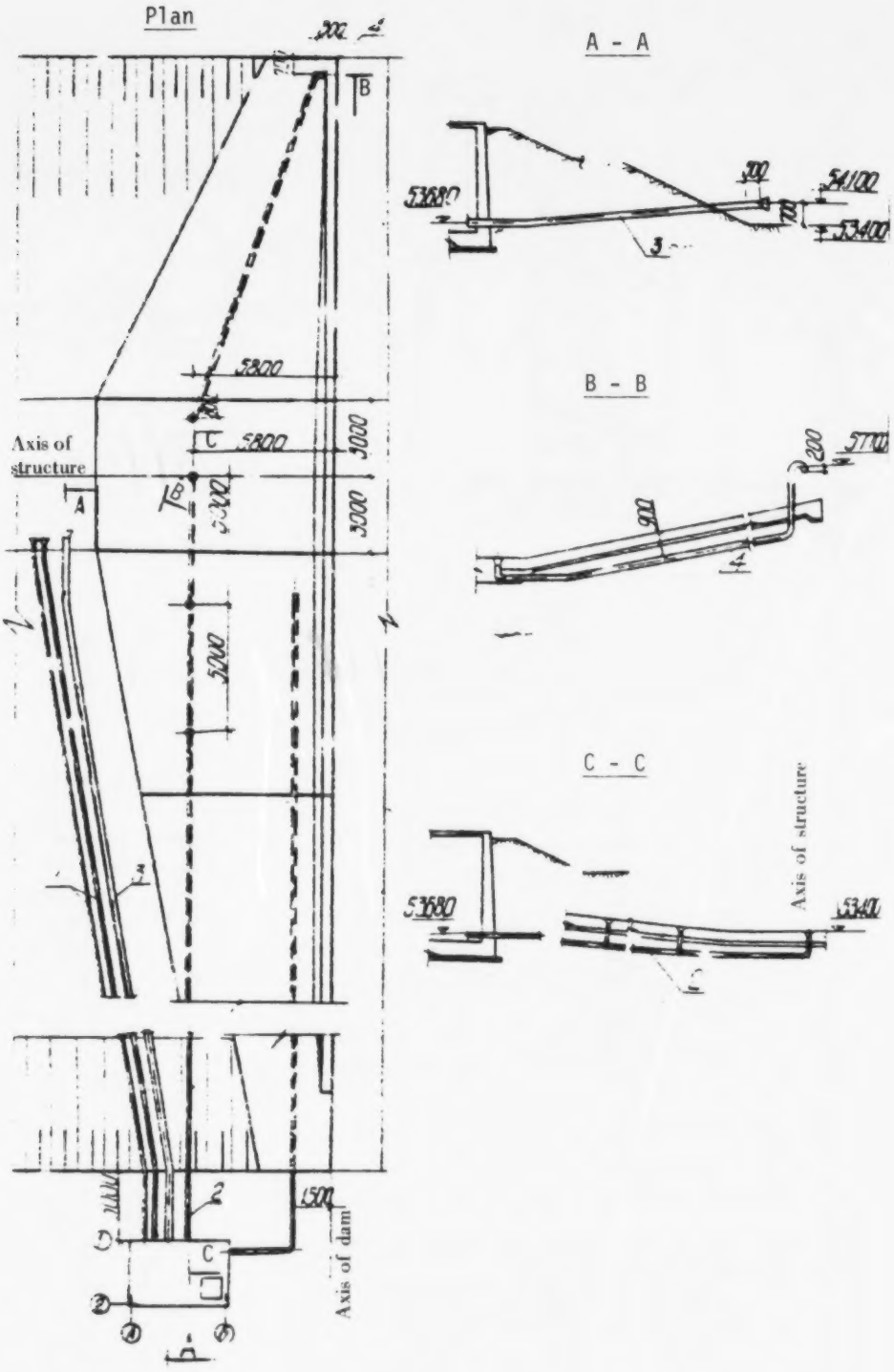


Figure 24. – Flexible dam on the Malaia Kuberle River. Layout of pipes. 1) conduits for level warning devices, 2) filling (and simultaneousiy discharge) conduit, 3) suction pipe.

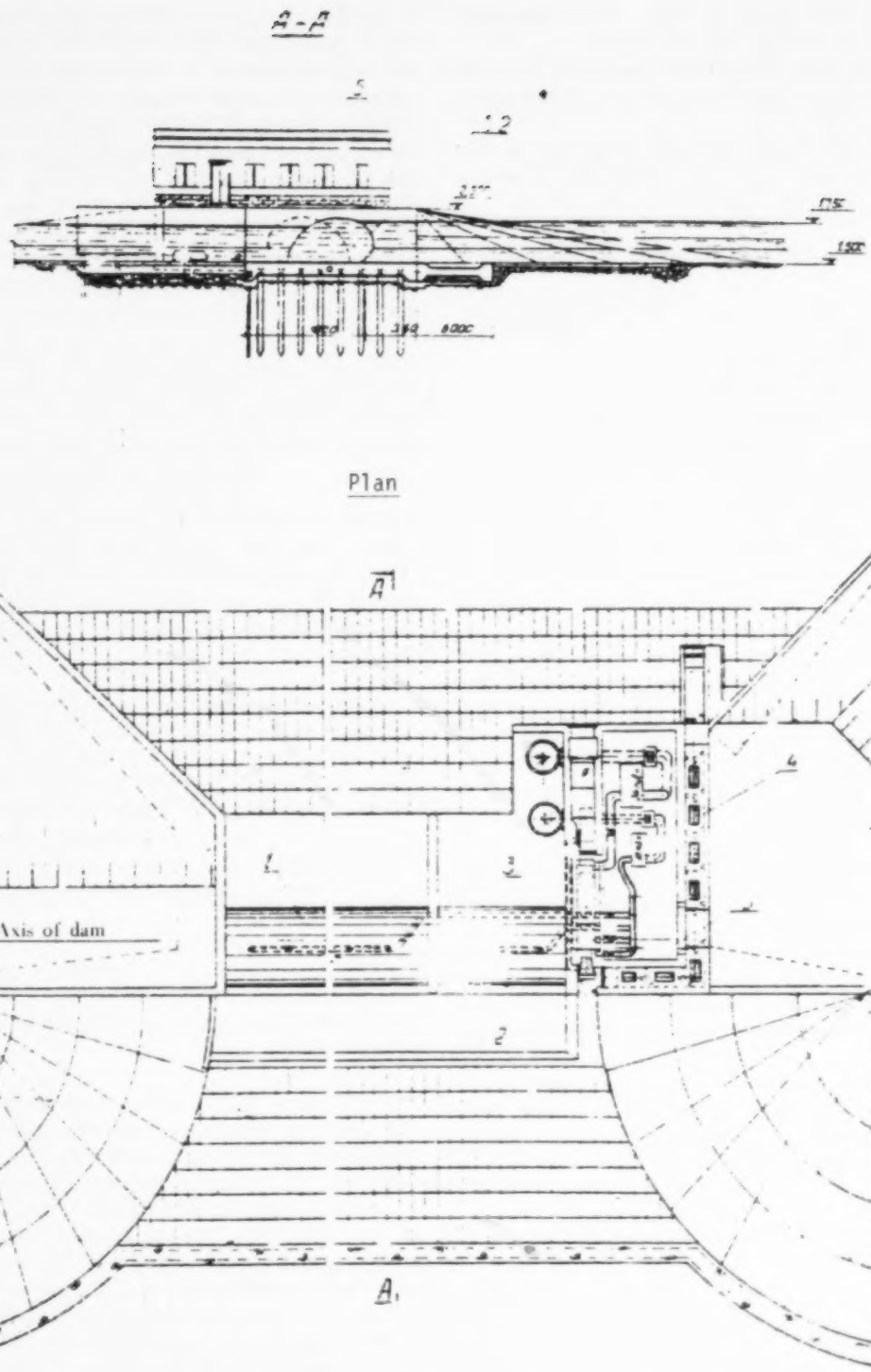


Figure 25. – Flexible dam in Mius Bay of Rostov oblast. 1) flexible dam, 2) flexible gate, 3) jet-deflecting fish screens, 4) slotted pan-type fish elevator, 5) pumping plant.

- Prevent the mixing of Mius River freshwater with Taganrog Bay salt water
- Allow passage of fish from Taganrog Bay into Mius Bay for spawning and then back again

The design of the complex was produced by the Southern Sci. Res. Inst. for Water Management Construction.

The complex is made up of the following structures:

- Earth dam
- Flexible inflatable dam
- Flexible inflatable gate
- Slotted staggered flow fish passage
- Hydromechanical fish passage
- Pumping plant

The flexible inflatable dam is mounted on a concrete apron and functions within the unit as a retention structure. Only in the flood season is the dam shell emptied and stowed on the conrete foundation.

The flexible gate is designed to create a constant flow of water from Mius Bay into Taganrog Bay for the purpose of providing passage for fish returning to salt water, and also to create the sound of a stilling basin to attract the fish to the inlet of the fish passage.

The pattern of the fabric for the dam and gate shells was based on the idea of attaching it only to the floor of the conrete part of the dam. This makes it possible to withstand water pressure from both Taganrog Bay and Mius Bay. Filling and emptying of the dam is effected with the same pumps used for the hydromechanical fish passage.

The system components operation, including the flexible dam and gate, is to be automated. The design parameters related to the flexible structures are presented in table 5.

Table 5. – Flexible dam and gate in Mius Bay, Rostov oblast.

Parameters	Units	Amount	
		Dam	Gate
Maximum discharge	m^3/s	510.0	102.0
Design head	m	3.25	3.25
Height	m	3.50	3.50
Length	m	50.0	10.0
Shell perimeter	m	12.1	12.1
Shell volume	m^3	1000.0	200.0

A number of designs incorporating flexible structures have appeared recently in the working drawing and specification stages: for timber rafting, Giprolestrans (State Institute for Designing Timber Rafting Mills and Lumber Transportation Routes, Leningrad) has designed auxiliary dams for a number of rivers; Giprorechtrans (State Institute for River Tansport Designs, Moscow) has published designs for reconstruction of the Faustovo and Andreevka hydrotechnical complexes; and Giprogor (State City Planning Institute, Moscow), in the section of the memorial park in the town of Shushenskoe from the bridge across the Shush' River to the V.I. Lenin museum, in compliance with special restoration requests, has proposed three variations of gate designs having spans of 180 meters, including two variations using flexible gates.

Worthy of attention is the Giprogor design for beach area and organization of public services along the foreshore of the Bol. Kinel' River in the city of Buguruslan (Kuybyshev oblast), using a flexible inflatable gate with a high-pressure flap (fig. 26).

An interesting design for bank protection and removal of obstructions on the Uzh River at Uzhgorod has been developed by Ukrgiprovodkhoz (Ukrainian State Planning, Design, and Scientific Research Institute for Water Management Construction). The design incorporates a flexible, automatically activated inflatable gate 3.5-meters high and 72-meters long (fig. 27). Its construction will begin in the future.

In addition to the flexible inflatable gates and dams that are in use abroad, widespread use of flexible membrane dams, gates, and flumes are being developed here.

In 1972 (June 15-17) at the All-Union Seminar on Cultivated Grazing Land held in Kazan', a flexible membrane dam being built on the Mesha River in Tatar ASSR, 2-meters high and having a span of 15 meters, was demonstrated. The dam consists of an upstream blanket, downstream spillway apron, and pressure panel, with its bottom edge attached to the blanket and top edge connected to a steel cable anchored on both banks. The resulting reservoir made it possible to irrigate 60 hectares of pasture land.

In the summer of the same year in Tatar ASSR on the Iinke River, a second membrane dam slightly

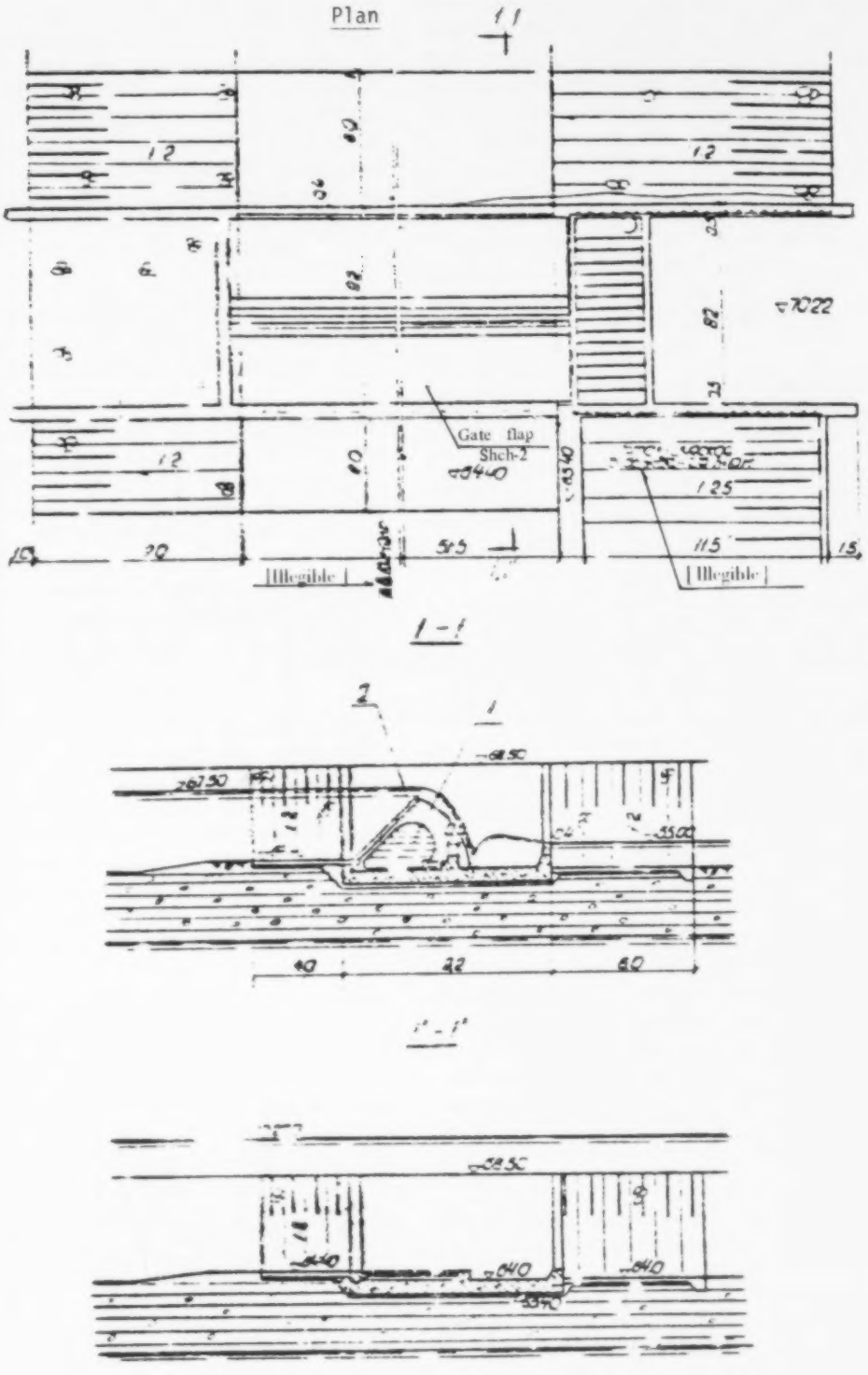


Figure 26. – Flexible dam on the Bol. Kinel' River. 1) shell, 2) metal flap.

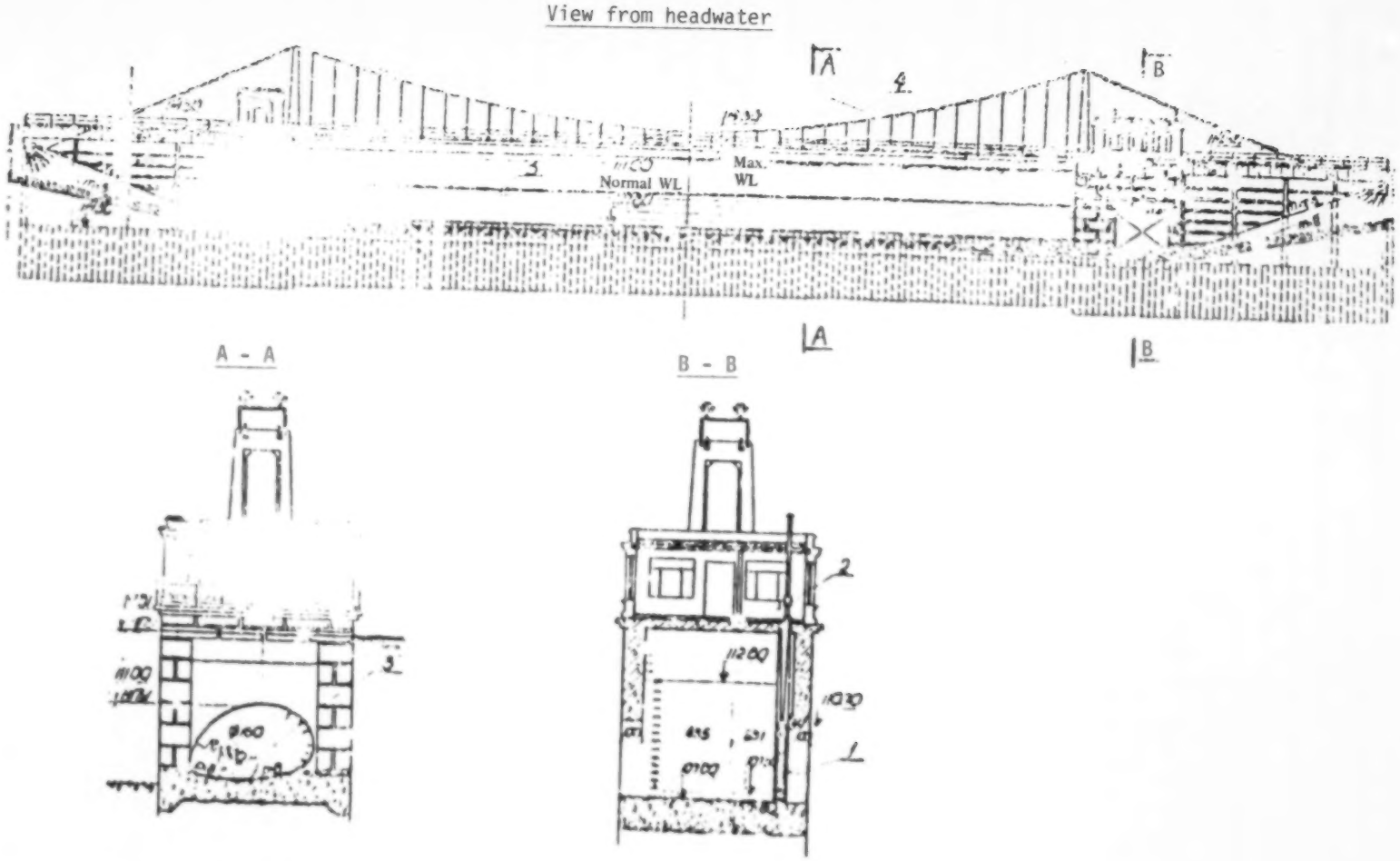


Figure 27. – Flexible gate on the Uzh River, Ukrainian SSR. 1) working gate, 2) gate hoist, 3) flexible gate, 4) suspension bridge.

different from the first was constructed, also for irrigation of grazing lands. The panel is 15-meters long and 3.5-meters high and its bottom edge is attached to a concrete cutoff embedded to a depth of 1.3 meters. The top edge is connected to a main chord consisting of a bearer cable and main cable in the form of parabolic segments and stays, uniformly, transferring the stresses from the panel (membrane) to the main chord, which in turn transfers all those forces to the shore anchors.

In winter, the dams are disassembled and stored in an enclosed shelter; in spring, after the spring runoff, they are reinstalled and operated.

The experience gained from operating membrane dams and gates has demonstrated the advantages of using structures with a load-relieving chord; in this case, the stresses are distributed evenly along the entire span, the material has no wrinkles; i.e., there are no compressive stresses. Flash floods can be passed over the shell, as took place on the Iinke River Dam or with the shell lowered, which can be accomplished by releasing the main chord from one or both shore anchors.

In 1972, Iuzhuralgiprovodkhoz (Southern Urals Planning, Design, and Sci. Res. Institute for Water Management Construction) designed a project for creating a reservoir on the Seleuk River in Ishimbai region of Bashkir ASSR, to be used for agricultural demands, irrigation of small plots, and the public welfare of villages for the purpose of compensating for water diverted from the Seleuk River basin by the Berkhornut-Sterlitamak aqueduct.

A reservoir of 61 200 m^3 at normal operating level will be created by an earth dam with embankments stabilized by riprap and a spillway structure consisting of a membrane gate 2.3-meters high and span of 26 meters, intended to discharge floodwaters to within 1 percent of 145 m^3/s and installed in a trapezoidal canal having bottom width of 21 meters and 1.25:1 side slopes (vertical to horizontal). The bottom and sides of the canal within the confines of the structure are made of cast-in-place reinforced concrete. This unit is under construction.

In 1973, NIMI produced a plan for spanning cuts through the Uch-Kosa Peninsula in Daghestan ASSR. The two-plan variations call for use of flexible membrane structures along a section 700 meters from the opening of the cut: according to the first variation, a cut 100-meters wide is spanned by a flexible membrane dam 5.7-meters high operating without overflow. Whenever necessary, to allow water through, the dam is collapsed onto the bottom. According to the second variation, the cut is spanned by a flexible membrane dam 4-meters high operating with overflow of 20 to 50 m^3/s. If floodwaters with large discharges occur, the membrane dam, as in the first variation, is collapsed onto the bottom, and the floodwaters are discharged by the natural channel (fig. 28).

As another alternative, the plan calls for placing riprap on an earth dam under a flexible membrane cover. After the riprap has been placed, the membrane structure can be disassembled and subsequently reused for holding or regulating the discharges of other canals and channels in the form of two 60- or four 30-meter dams.

Whereas it was previously believed that the span covered by membrane structures was limited to 40 to 50 meters, in the plan for spanning the cuts through the Uch-Kosa Peninsula, it has been shown feasible to use membrane structures 100 to 200 meters and larger by dividing them into a number of independent sections joined at the construction site with an assembly seam. The top main chord is attached, not only behind the shore anchors, but also behind intermediate spurs in the form of caissons or piles.

Experience gained from the use of flexible membrane structures in the forestry industry (Central Sci. Res. Inst. for Logging, Leningrad) has proved useful. In 1969-72, researchers from this institute tested three dams on the Shen'ga, Chermoz, and Zalesnaia Lala Rivers. The first two were made of canvas, and the third of rubberized fabric with strength along the warp of 11 t/m, height up to 2 meters, and span up to 40 meters.

The universal dam of the curtain type (UPZT, not a very apt designation) differs from the membrane dam we have proposed in that the downstream edge of the support panel is not fastened to the flexible blanket, but rather to a downstream supporting surface (foot block) running from one bank to the other in a manner similar to the upstream structure.

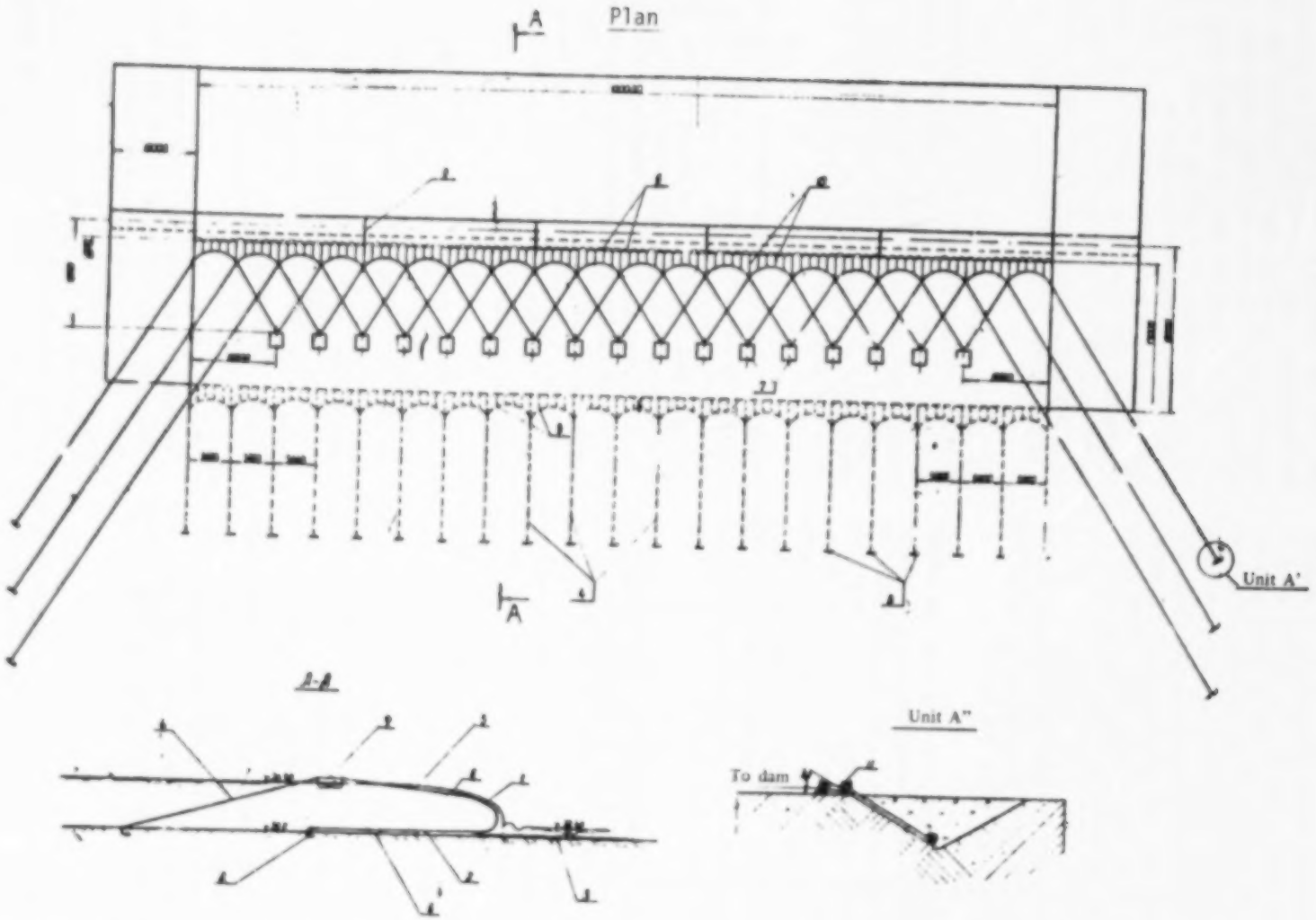


Figure 28. – Membrane dam on the Uch-Kosa in Daghestan ASSR. 1) membrane dam, 2) upstream blanket, 3) downstream apron, 4) anchor cable, 5) bearer cable, 6) main chord, 7) caisson, 8) anchor, 9) assembly joint, 10) stays, 11) tensioning device.

Because of vibrations in the dam, when water passes over, the TsNILesosplava design has limited application.

The NIMI and IuzhNIIGiM maintain a close relationship with many water management design, construction, and service organizations throughout the U.S.S.R.

Thus, to protect the Novotroitsk Reservoir from "thermal" pollution, the Stavropol' State Regional Powerplant, in 1976, proposed and initiated construction of a flow deflector in the form of a membrane dam 150-meters long and 5-meters high with perforation over the entire section that disperses the heated discharge from an outlet canal in the surface layer of a cooling pond.

The dam is stabilized by a flexible upstream blanket weighted down by concrete slabs. The rectilinearity of the structure in the plan is provided by a main chord in the form of air-filled flexible tubes 1.2 meters in diameter.

Creation of this structure from flexible synthetic fabrics to regulate the flow at 94 m^3/s, not only did not increase the cost of constructing and operating it, but actually reduced those expenditures by a factor of 5 as compared to a filter dam of sorted rock and has a positive effect on the thermal and biological conditions within the pond. It should be noted that with the passage of time, a filter dam (the previous type) becomes an overflow dam, due to clogging of void spaces with sediment, disrupting the planned mode of operation of the stucture (reduction in flow, eddies).

A set of hydrotechnical measures to prevent erosion and restore the fertility of eroded lands is being developed for the Iavano-Obikiik Valley in Tadzhik SSR. Eventually, a large erosin barrier will be created out of flexible structures in the form of large-scale cable networks encased in synthetic materials. The design, produced by Giprovodkhoz, calls for construction of 60 flexible dams each 10- to 15-meters high with spans of 70 to 100 meters.

In our country, problems at the Kerchenskiy and Dnepr-Bug hydroelectric projects and in the Kara Bogaz Gol are similar to those in Venice, and so the use of flexible structures is a real alternative. One has already been drawn up at IuzhNIIGiM, and interesting design solutions to actual engineering problems have been found.

In the U.S.S.R., widespread use is being made of flexible membrane and inflatable dams and gates, especially to create impoundments for irrigation of grazing lands. To date, the Ufa Rubber Plant has manufactured more than 70 such structures with spans of 20 to 30 meters and heads up to 4 meters. To achieve broader use of the experience gained from using flexible structures, co-workers at NIMI, IuzhNIIGiM, and the Ufa Rubber Plant have compiled standard drawings for 40 typical flexible membrane and inflatable dams (figs. 29 and 30). If it becomes necessary to enlarge the span, several of the same kind of sections are joined together into a single construction by means of an assembly seam.

As demonstrated by 5 years of experience in operating flexible inflatable and membrane structures, inflatable dams and gates are recommended for use in large spans and when precise regulation is required; membrane dams are more reliable in operation, but are less maneuverable.

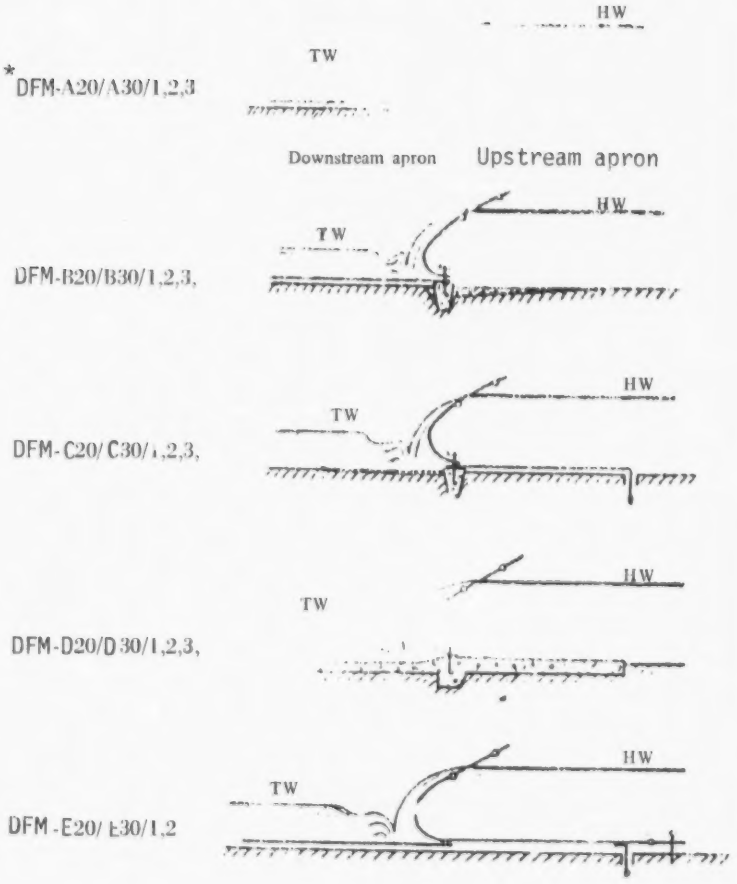
Net structures incorporating synthetic materials are being more widely used in reclamation construction now. Important results in this direction have been obtained by co-workers of the Hydraulic Structures Department at the Kherson Agricultural Institute, working under our direction.

It is proposed that a portable gate be used in place of the metal sluice gates with screw lifts, designed by Giprovodkhoz and Sredazgiprovodkhoz and weighing 35 to 45 kilograms, that are installed to maintain the water level in the races of flumes in irrigation systems. The sluice gate is a strip iron framework jogged in parabola form to which a sheet of flexible waterproof material is bolted. The sheet passes 3 to 4 centimeters beyond the edge of the framework and serves as a seal when the gate is placed in the flume.

Rubber can be used as the seal. Using shore anchors, the gate framework is situated on the ends of the flume and inclined 60 degrees in the direction of flow.

The sluice gate provides the required head in the headwater; flowthroughs and surplus discharges are allowed to flow over the top rim of the gate, as over a sharp-crested weir.

The weight of the gate is 4.8 kilograms and it is easily installed in the flume within 10 to 15 seconds. Portable gates of this design underwent

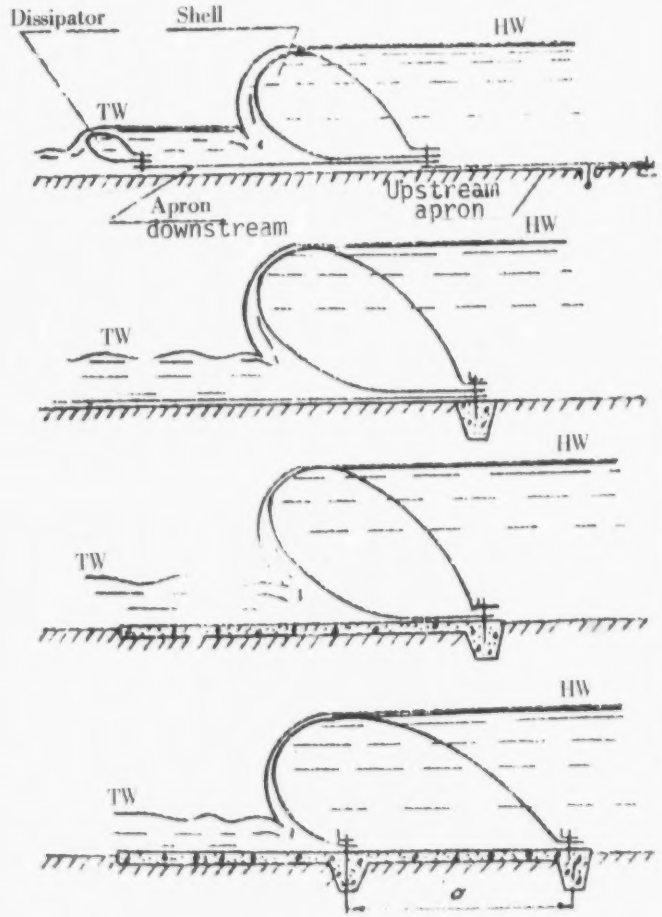


Dams, flexible membrane

No.	Index of dams	Overall dimension: Water levels	Overall dimension: Length	Membrane: Width	Membrane: Thickness	Downstream apron: Length	Downstream apron: Width	Upstream apron: Length	Upstream apron: Width	Order number	Ruble Price in thous.	Amount of fabric required: Fabric 4.2 m	Amount of fabric required: Any kapron fabric
1	DFM-A	1	20	2	40	20	4	20	4	DFM-A20/1	5.0	70	210
2		2	20	3	40	20	6	20	6	DFM-A20/2	8.9	130	420
3		3	20	4	40	20	10	20	10	DFM-A20/3	12.0	190	570
4		1	30	2	60	30	4	30	4	DFM-A30/1	7.2	100	315
5		2	30	3	60	30	6	30	6	DFM-A30/2	13.4	150	630
6		3	30	4	60	30	10	30	10	DFM-A30/3	18.0	200	850
7	DFM-B	1	20	2	40	20	4			DFM-B20/1	5.6	10	30
8		2	20	3	40	20	6			DFM-B20/2	8.1	140	420
9		3	20	4	40	20	10			DFM-B20/3	10.8	190	570
10		1	30	2	60	30	4			DFM-B30/1	9.6	130	450
11		2	30	3	60	30	6			DFM-B30/2	9.3	150	630
12		3	30	4	60	30	10			DFM-B30/3	11.9	190	850
13	DFM-C	1	20	2	40			20	3	DFM-C20/1	4.2	70	60
14		2	20	3	40			20	6	DFM-C20/2	5.4	100	180
15		3	20	4	40			20	9	DFM-C20/3	7.6	140	270
16		1	30	2	60			30	3	DFM-C30/1	4.5	80	135
17		2	30	3	60			30	6	DFM-C30/2	6.1	150	270
18		3	30	4	60			30	9	DFM-C30/3	11.4	200	400
19	DFM-D	1	20	2	40					DFM-D20/1	4.8	70	-
20		2	20	3	40					DFM-D20/2	6.6	100	-
21		3	20	4	40					DFM-D20/3	9.5	140	-
22		1	30	2	60					DFM-D30/1	7.6	100	-
23		2	30	3	60					DFM-D30/2	10.0	150	-
24		3	30	4	60					DFM-D30/3	13.5	200	-
25	DFM-E	1	20	5	40	20	4			DFM-E20/1	8.2	150	120
26		2	20	9	40	20	6			DFM-E20/2	11.4	210	240
27		1	30	5	60	30	4			DFM-E30/1	9.2	230	180
28		2	30	9	60	30	6			DFM-E30/2	17.2	400	360

*Editor's note: DFM – Dams, Flexible Membrane. /SHS/

Figure 29. – Diagrams for standard plant drawings for membrane dams.



Dams, flexible inflatable

No.	Dimensions / Dam index	Difference in water levels	Upstream apron	Downstream apron	Energy dissipator	Shell	Length of section	Bolt spacing	Number for ordering	Cost in rubles	Amount of fabric, m² Woven fabric	Any Kapron fabric
1	* DFI-A	1	8	4	2	5	15		DFI-A1	9.4	160	200
2		2	16	8	2.5	10	15		DFI-A2	17.6	272	340
3	DFI-B	1	8			5	15		DFI-B1	4.5	144	180
4		2	16			10	15		DFI-B2	12.9	225	360
5	DFI-C	1				5	15		DFI-C1	3.8	114	
6		2				10	15		DFI-C2	7.5	225	
7		3				15	15		DFI-C3	10.2	340	
8		4				20	15		DFI-C4	15.0	450	
9	DFI-D	1				5	15	2	DFI-C1	3.8	114	
10		2				7	15	3	DFI-C2	5.1	158	
11		3				10	15	4	DFI-C3	7.5	225	
12		4				13	15	5	DFI-C4	10.2	318	

*Editor's note: DFI stands for Dams, Flexible Inflatable. /SHS/

Figure 30. – Diagrams for standard plant drawings for inflatable dams.

tests in 1971 in the flume system of the collective Krupskaia farm in the Nizhnegorskiy region of the Crimea oblast', and are now beginning to be used extensively.

A flexible cofferdam, in the form of a flexible membrane dam, only on a smaller scale, can be used successfully to raise the water level in a canal near a siphon or pipe outlet.

The size of the cofferdam is 4.5-by 1.5-meters for a canal capacity of up to 600 liters per second. In the top part, the material is bonded double and has a channel 80 millimeters in diameter through which is passed a rod 10 to 12 millimeters in diameter with rings on the ends. Through the rings are passed wire pins made of steel with circular cross section 25 to 30 millimeters in diameter and 900 to 1000 millimeters long with sharpened ends. On the upstream side, the edge of the blanket is fastened with small metal pins to the bottom and sides of the canal (figs. 31 and 32).

Besides solid cofferdams with crest overflow, in some circumstances it is necessary to have flexible cofferdams with slotted water discharge for through passage of water without raising the water level in the canal. For this, several slits 50-millimeters wide and 20- to 25-centimeters long are cut in the fabric 20 to 30 centimeters from the top edge in the middle of the cofferdam, or a single overflow opening to the 20- to 25-centimeter height is made on the top edge. The slot cutouts must be rounded along their entire perimeter with lapped over material or otherwise reinforced.

On the upstream side, the slot outlet is covered with a piece of flexible material 80- to 90-centimeters wide and 70- to 90-centimeters long, the top edge of which is attached to the cofferdam. When this type of flap is lowered, it is tightly pressed against the slot cutouts by the water and effectively shuts off the cofferdam. In those instances when water must be allowed through the cofferdam, the bottom edge of the flap is raised or turned inward the necessary amount, and then water passes through the open slots.

Flexible cofferdams also can be used as gauges. The accuracy of the measurements is enhanced if flexible orifice meters in the form of short conical hoses are used.

Hydraulic tests have shown that the coefficient of discharge of flexible conical orifices is equal to 0.86. A nozzel with inlet opening diameter of 48 centimeters, outlet diameter of 25 centimeters, and length of 50 centimeters should be used for measuring discharges up to 100 liters per second.

This cofferdam design can be used to create the backwater in an irrigation ditch and in furrows when watering with siphons. In this case, it is necessary to have spreaders at the end of the nozzle to regulate the discharge.

Cofferdams with flexible nozzles underwent tests in the summer of 1971 on the intrafarm (irrigation) system of the collective farm im. Krupskaia in Nizhnegorskiy region of the Crimea oblast', and are now being manufactured.

Also deserving of attention are the automatically activated designs being developed by co-workers in the model and experimental design section of Kuban'giprovodkhoz (Kuban' Planning, Design, and Sci. Res. Inst. for Water Management Construction), who are working under our supervision.

The special conditions of rice farming make it necessary to maintain a specific level of flooding in the paddies. According to data from VNIIRis (All-Union Sci. Res. Inst. for Rice Cultivation), total expenditures for regulating the water level in paddies comprise 64 percent of all expenditures following planting.

Presently, automatic headwater and tailwater level-regulating gates, developed by E. E. Makovskiy, are in use on several rice irrigation systems in Krasnodar krai. These devices have a number of significant drawbacks:

- Designs of the automated structures substantially reduce discharge capacity.
- Special precast reinforced concrete structures are required, which is in conflict with unification and industrialization of construction.
- The command-servo system is complex, thus necessitating a considerable (up to 30 cm) hydraulic gradient.

In our opinion, structures incorporating flexible materials have no drawbacks, e.g., a flexible water-filled gate having openings on its upstream face through which it is spontaneously filled with water —as a function of head. Openings are provided on the shell crest to allow air escape. The shell is connected to the tailwater by an overflow pipe

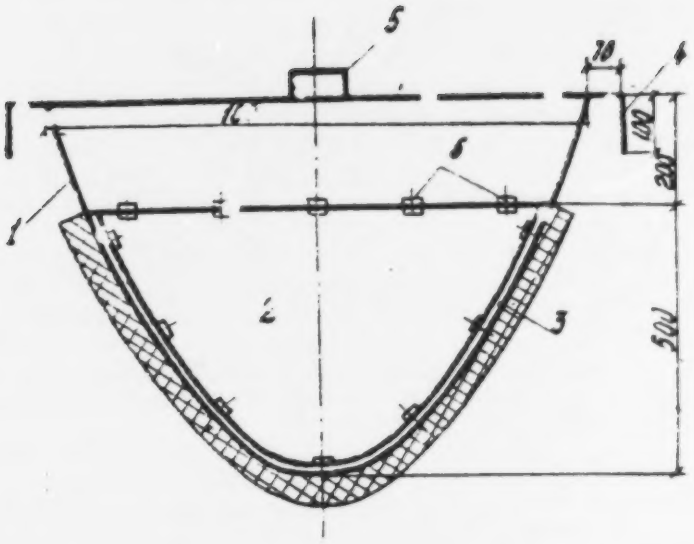


Figure 31. – Section. 1) pressure panel, 2) upstream blanket, 3) shroud, 4) pins, 5) steel cable or rod, 6) tensioning devices.

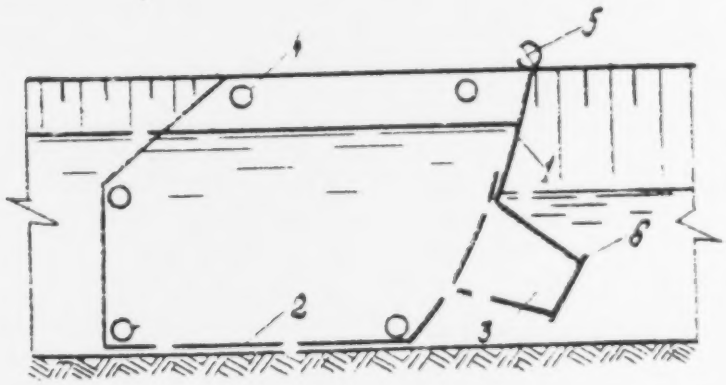


Figure 32. – Diagram of flexible gate on sluice from irrigation ditch into check. 1) shell, 2) shell cavity, 3) intake opening, 4) air intake opening, 5) drain pipe, 6) float-type level gauge.

through which water can be discharged from within the shell. The degree of opening of the overflow pipe is controlled by a level gauge. When the desired level is reached in the tailwater, e.g., in a paddy, a float shuts off the outlet of the overflow pipe, the shell begins to fill, and the overflow opening of the structure is closed off. When the level in the tailwater drops, the float exposes the outlet of the overflow pipe, water from the gate shell is poured into the tailwater, and the shell assumes a flat position, corresponding to the shape of its apron.

Another automatic gate design is a flexible gate of composite design with an overflow in the form of a standard shutter weir, in which the upstream panel is made of flexible materials (fig. 33).

The principle underlying its operation is as follows: for instance, begin the initial position of the gate (which is deflated) with water flowing into a rice paddy. When the desired level is reached in the paddy, the level gauge is activated (floats), obstructing the outlet opening of the overflow pipe. Due to the difference in pressures (external and

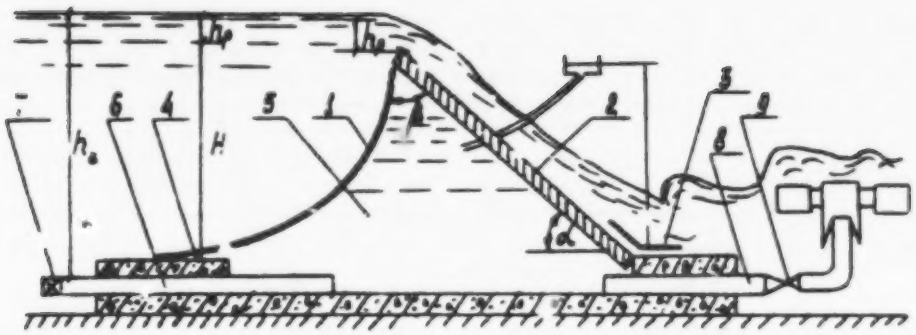


Figure 33. – Flexible composite-type regulator (MRKT) with overflow panel. 1) flexible shell, 2) rigid panel, 3) flexible hinge, 4) concrete apron block, 5) regulating space, 6, 8) filling and emptying pipes, 7, 9) slide valves.

internal in the gate chamber), water begins to pass through the inlet into the gate chamber; the gate rises. Excess air is vented through an opening provided on the top rim of the overflow panel. The degree of elevation of the gate is restricted by the length of the upstream panel (membrane). Lowering of the gate takes place in the reverse order; i.e., with a lowering of the water level in the tailwater, the level gauge is activated, exposing the outlet opening of the overflow pipe; water from the gate chamber enters the tailwater and the gate is lowered. The inlet opening remains open the entire time.

Installation of an L-shaped pipe inside the overflow pipe of a composite flexible gate makes it possible to maintain the required level, not only the tailwater, but in the headwater as well.

The automatic gates described above can be installed in the various types of hydrotechnical structures.

The automatic gate of composite design shown on figure 33 is used in irrigation systems in Central Asia. The production of flexible pipelines that can be used in various spheres of the national economy grows each year. They are being used extensively in our country for both border strip and furrow irrigation. Depending on local conditions, flexible pipes possess different parameters (length and diameter). From a batch, of 1000-running meters, of flexible piping is produced 5 or 10 separate watering sections, each of which has a siphon or other diversion structure with total water discharge of 600 to 1200 liters per second. The headworks of the irrigation section has a flexible pipe 420 to 460 millimeters in diameter, 350 or 420 millimeters in the middle, and 300 or 350 millimeters at the end.

The cost of such irrigation conduit with identical length is equal to the cost of conduit with the diameter of the middle section. Use of flexible conduits having variable diameter for the same discharge capacity lowers their cost by a factor of 1.5 in comparison with conduits of identical diameter.

Using flexible pipes considerably facilitates design, construction, and operation of irrigated plots with few waterings and greatly reduces the amount of time needed to put them into production. Using flexible conduit to supply water to sprinklers eliminates the temporary irrigation system, greatly reduces seepage losses, prevents clogging of machines and sprinklers by wet soil, and extends their service life. Flexible pipes can divert water from irrigation ditches and supply it to any location in case of urgent need.

Despite the broad range of application of flexible conduits, further expansion of their use in construction practice is being held up by the quality and limited quantities of manufactured items. Presently, flexible conduits are being manufactured from fabric Kapron 1539 (reclamation fabric is an unfortunate choice of terms because it is not just used in reclamation). Tensile strength along the warp is 4 t/m — allowing for a safety factor of 5 to 8 (dynamic loads, long-term strength) — which (Kapron) reduces the design strength to 0.8 to 0.5 t/m, and as a consequence, only 2- to 2.5-meter H_2O pressure can be created within the shell, which obviously is inadequate.

Flexible flume canals are beginning to be used to transport water and corrosive chemicals; these consist of two parallel water-filled or air-inflated flexible pipes with a horizontal impervious insert and the working fluid between them. Such designs were first tested in 1971, both in the laboratory (NIMI) and in the field (VolzhNIIGiM).

This is hardly a complete survey of the application of flexible structure in hydrotechnical construction. Even newer designs are appearing along with the use of modern materials. Widespread adoption of flexible structures in the most diverse branches of the construction industry will make it possible to:

- Reap a great economic benefit
- For the national economy, conserve a large amount of scarce and expensive materials
- Reduce the amount of capital invested in the construction of a number of structures
- Improve the quality of construction work
- Accelerate the startup of individual types of structures
- Expand the use of transportation and improve mechanization
- Raise productivity

SPECIAL QUESTIONS REGARDING OPERATION

Moderate experience in the construction of flexible dams has permitted us to compile brief instructions concerning their installation, operation, and storage that may be extended to other flexible structures.

Operating Rules

In the process of operating flexible dams, it is necessary to observe the following rules:

- During installation and disassembly, it is not permitted to drag the dam about, to use sharp objects or instruments on it, or to step on it.
- It is not permitted to contaminate the dam with lubricants, kerosene, gasoline, acids, alkalis, and other substances harmful to rubber and textiles.
- It is recommended that the dam be shielded from direct sunlight and from sand and dirt.
- The area on which the dam is unfolded for inspection and repairs must be clean. It is recommended that it be covered with bedding materials.
- It is not permitted to fold or unfold the dam at temperatures below −10 °C.
- The base in the streambed on which the dam is installed must be as horizontal and smooth as possible; no sharp objects (rocks, wire, etc.) can be present.

Just before the dam is filled, it is necessary to remove it from its sheath and spread it out, over the preparation site; carefully inspect it and make sure damage has not occurred. After the inspection, it must be transported to the installation site, and then the shell, downstream apron, and upstream blanket are accurately secured on the side slopes and in the channel, and wrinkles are removed.

The dam shell can be filled with standard pumping equipment or by gravity.

Flexible dams should be stored in a clean, dark place. The air temperature in the storage area should be −25 to +25 °C. Temporary storage of the dam at temperatues up to +50 °C is permitted. In the warehouse, dams should be stored partially unfolded on shelving without packaging sheathes.

Dams that have been in operation and planned for storage must be washed clean and carefully dried under shade in the open air or under shelter. Dams with mechanical damage or leaks in the inner or outer rubber coating must be repaired before storage.

Transportation

Dams are transported manually or by vehicles at the storage and worksites. Never drag dams over the ground from place to place.

Strict procedure must be followed when inserting a dam in its storage pouch: the dam is spread out with the shell on top; the upstream and downstream apron panel is placed over the shell; it is folded over in the middle, and then it is rolled up on a spool.

The dams are transported by railroad in pouches and crates. When packing a dam in crates, special care must be exercised to prevent damage to the dam by nails and other sharp objects.

Dams are transported by motor vehicle in pouches or in unfolded form on canvas; in this case, the vehicle body must contain no sharp objects as well as chemical solvents and oils.

Repair of Dams in the Field

Flexible dams can be damaged in the following ways while in operation: punctures or tears in the dam shell; damage to the rubber coating of the fabric; peeling off of sealing strips.

The repair sequence for flexible dams is as follows:

1. All rubberized fabric dams having damage and subject to field repairs are cleaned carefully on both sides and completely dried. The repair is carried out in a clean area shielded from direct sunlight and wind at 10 to 25 °C.

2. The places in the dam needing repair and reinforcement surfaces (patches) of the base fabrics to be bonded are worked (made rough) with emery paper or other abrasive material.

3. All surfaces to be bonded (glued) are rubbed with a clean rag soaked in benzine solvent, acetone, or pure water and wrung out and dried.

4. The surfaces being bonded are coated twice with a thin layer of adhesive (cement) and allowed to dry for 10 to 15 minutes after each application.

5. The glued patches and strips are firmly pressed together and worked with a roller. The repaired spot is lightly dusted with talc.

Punctures and tears no longer than 100 millimeters are repaired by cementing strips (patches) of the base fabric onto the inner surface of the dam. Reinforcing strips of the base fabric are cut out so that they cover the damaged area by no less than 50 millimeters on all sides. The dark side of the fabric is roughed up and coated with cement. Afer bonding, the edges of the reinforcement are taped down with tape No. 1100, 20-millimeters wide. On the exterior surface, the damaged spot is taped shut with tape No. L-61, 60-millimeters wide.

If the puncture or tear is longer than 100 millimeters, it is patched on the exterior surface with a reinforcement strip made from the base fabric covering the damaged area by no less than 30 millimeters on all sides. In this case, the light side of the reinforcement is roughed up and coated with cement, and its edges are taped down with tape No. L-61, 20-millimeters wide.

Damage to the outer rubber coating of the fabric of a flexible dam is repaired with patches made of L-61 tape.

It is recommended that damage to the inner rubber coating of the dam fabric be sealed off with patches made of rubber tape No. 1100. The patches should cover the damaged rubber layer by no less than 90 millimeters on all sides.

Places where tape has separated from seams are repaired in the same manner as punctures and tears. If a large amount of tape has separated, the old tape is removed entirely and new tape applied. The end of the tapes should overlap 20 to 30 millimeters.

To increase the reliability of a repaired dam, it should not be exposed to water for at least 2 days following repairs.

When necessary, the dam shell can be filled with water 1 to 2 hours after repair, but it should be repaired again later according to the set schedule.

ECONOMIC EFFECTIVENESS OF USING FLEXIBLE STRUCTURES

SIGNIFICANCE TO THE NATIONAL ECONOMY OF GROWTH OF MANUFACTURE AND APPLICATION OF FLEXIBLE STRUCTURES

Extensive application of synthetic materials in the national economy is one of the effective means of accelerating technical progress and cutting down on labor in all spheres of materials production.

The use of synthetics in industry and construction signifies a giant step forward in the growth of technology, is improving and accelerating engineering processes, is contributing to improvements in the design of machines and equipment of higher quality and reduced production costs, and is making a rise in output per worker-hour possible. Adopting the latest advances in chemistry by manufacturing and construction is a matter of great state concern.

Construction and agriculture account for around 50 percent of the volume of synthetics used. Enormous potentials opened up by the use of advanced materials in construction derive from their lightness, good heat- and sound-insulating properties, waterproofness, and high specific mechanical strength.

The main advantages of using synthetic materials in construction consist in a sharp reduction in the weight of structural elements, a reduction in labor hours, cost and capital investment needed for their manufacture, and a savings of metal, cement, wood, and other materials. The use of synthetic materials will make it possible to convert to industrial construction methods, simplify and facilitate construction and assembly operations, enlarge the dimensions of precast structures due to their diminished weight, and, in many instances, avoid the use of heavy-duty hoisting and hauling equipment.

The special properties of flexible building structures will make it possible to implement architectural and planning innovations that are out of the question when antiquated construction materials are used. Their most important guarantee in terms of outlook and development is conformity to progressive construction principles (best results from the least expenditures).

LONG-RANGE PROSPECTS FOR USE OF FLEXIBLE STRUCTURES

Flexible structures, possessing a number of positive qualities that distinguish them from fundamental hydrotechnical structures, in the future will occupy a worthy place in the various branches of water management. In the first place, they evidently will be used to regulate local runoff. This is explained by the fact that, in using local runoff, especially for purposes of irrigation and flooding, the runoff must be regulated quickly so the water can be used during a dry period. Earthfill embankments and concrete or reinforced concrete discharge structures are currently built for local use. The process of erecting such structures is labor intensive and construction materials are scarce, and often unavailable to collective and state farms, especially those located a distance from main transportation lines. The construction of reservoirs with earth dams and with earth-lined discharge channels are prone to failure and lead to washouts and gullies; in the final analysis this results in the destruction of the artificial ponds and reservoirs.

The use of flexible structures will considerably simplify the creation of collective farm ponds and reservoirs. Flexible structures can replace earth dams and concrete escapes, impounding a definite volume of runoff and discharging excess high waters. However, it should be kept in mind that replacement of an earth dam with flexible structures is possible when creating heads up to 3 meters. If it is necessary to create heads exceeding 3 meters, an earth dam is constructed, which can provide heads of 5 meters, 10 meters and higher, and the flexible structures are used for the escapes designed to allow passage of excess high waters. In this case, the flexible structures will replace expensive traditional escapes. They will be able to replace races, falls, or cascade drops. Practice indicates that more than 50 percent of the cost of a hydroproject is related to its outlet works. Thus,

replacing these expensive structures with flexible structures will lower the cost of control structures many times over.

The following advantage should be kept in mind when creating ponds and reservoirs with flexible structures. Very frequently, constructed dams and outlets can provide regulation of a specific volume of runoff but, as a result of careless geological explorations, excessive seepage of water through the bottom of the created reservoir is observed, and so water is not held for very long. In this case, the invested capital is lost. The use of flexible structures makes it possible to abandon a pond in a given location in the event of large seepage losses, and without any particular additional expenses, relocate it at another site where wasteful water losses will not occur.

The use of flexible structures in the construction of channel ponds and reservoirs in arid areas on the Steppe (the vast regions of the Zavolzh'e, that region to the east of the Volga, Kalmyk ASSR, Rostov oblast, Stavropol' krai, etc.). At present they are being constructed by piling up earthfill embankments that check the flow of steppe rivers. Such an earthfill cofferdam impounds a definite volume of water, which is used in the dry period of summer for irrigation, drinking water, and flooding. Such a cofferdam exists until high water, when it generally is washed away, and then the next summer it becomes necessary to build another dam. As a result, every year it is necessary to perform a large amount of earthmoving work, not to mention that the washed out earth dams silt up the river channels.

The use of flexible structures, in these cases, will make it possible to create run-of-the-river ponds and reservoirs without erecting earthfill cofferdams. At the end of summer, such a flexible structure can be hauled away, and in spring, at the moment high water appears, it can again be put in place. Replacing the earthfill cofferdam with a flexible structure can considerably reduce unprofitable expenditures for annual erection of a check structure. When irrigation is based on local runoff, the question of saving irrigation water becomes especially urgent because the volume of water that can be stored is restricted by the capacity of the ponds and reservoirs.

Flexible structures in the form of flexible flume canals, flexible hoses and conduits also can be used for purposes of conserving irrigation water. The advantage of such structures over stationary concrete and reinforced concrete or metal structures is that the very same flexible-flume canal or conduit can be used on another irrigated site whenever watering is ended.

Flexible structures also can be used extensively for river basin irrigation. In this case, the main advantage of flexible structures is the ease with which they are transported and erected, because flooded basin irrigation takes place only once (performed in early spring during runoff). At present, earthfill embankments as well as expensive concrete and reinforced concrete hydrotechnical structures are used for spring flood irrigation; the earthfill embankments retain a specific volume of water needed for designed watering of soils. The surplusing works provide for emptying of the basin in deep-water systems, also discharging surplus floodwaters in both deep-water and shallow-water systems. So, the structures that provide basin irrigation are only in operation several days out of the year, and the rest of the time, they stand idle, deteriorating; therefore, every year, major repairs must be made on them and they must be monitored carefully throughout the year. The great advantages of flexible structures for basin irrigation are obvious.

In the construction of deep-water basin systems, flexible structures can function as run-of-the-river check dams, helping to create more efficient conditions for irrigating the basin because as the basin fills to the design depth, the surplus floodwaters are allowed over the flexible dam by lowering its crest, achieved by releasing the water or air from it (depending on what the regulating part of the shell is filled with). This is the great advantage of a flexible structure because now, practical cases are encountered in which floodwaters discharged by a steppe river can last a month or more, which leads to the necessity of impounding water in the basin and discharging water through it during the entire flood season. Water standing in a basin for such a long time causes the planting season to be shorter.

Moreover, flexible structures in a system of deep-water basins can be used as escapes. Here, they function as spillways, and if necessary, the dam crest can be lowered to zero. In such instances, the flexible spillway-escape is installed in the lowest part of the basin. In this manner, these structures can completely replace escape sluices, which at the moment are major expenditure items

in hydrotechnical construction. With such arrangement of structures in a deep-water basin, it is no longer necessary to construct additional structures designed to discharge surplus floodwaters, thus reducing the cost of basin irrigation considerably.

Flexible structures can replace earthfull embankments in the construction of shallow-water basins as well. They are made in the form of flexible shells that assure creation of a layer of water up to 1 meter deep. Such shells are erected in early spring just before onset of the spring runoff, and are filled with either water or air, and then after the high water has subsided and the stored water has been absorbed into the basin, they are removed and stored away until the following spring. Replacing earthfill embankments with flexible shells also makes it possible to discharge surplus floodwaters directly over the crests of these shells without constructing additional structures. Farms, having similar shells at their disposal, can effect basin irrigation on different plots that are suitable for this type of operation.

Flexible structures can be used in shallow-water basins in the construction of stepped systems. Flexible structures, replacing embankments, make it possible to utilize areas with considerable gradients, where construction of basin irrigation was impossible before. Earthfill embankments are constructed at certain intervals established for convenience in mechanizing agricultural operations, and between them intermediate borders made of fabric are placed just before the onset of spring floods. These borders are made either in the form of flexible shells or flexible cofferdams. After the high water has subsided and the stored water has soaked into the soil, the temporary borders are removed and stored away until the following spring.

Flexible structures also can be used in the construction of spawning, feeding, and breeding ponds. Use of these structures in the form of cofferdams or shells considerably improves mechanization of pond surface preparation, allowing them to be emptied in the shortest amount of time without the use of expensive hydrotechnical structures.

The high rates of growth of industrial and agricultural production and of transportation, the improved well-being of the population, and widespread realization of the achievements of the scientific and technical revolution are placing greater demands on the quantitative and qualitative characteristics of water resources. The increase in production capacity often outstrips the construction of water storage and purification facilities, and in certain oblasts and regions of the U.S.S.R., the water storage facilities are not in any condition to treat the volumes of waste water that are being produced, and so water sources are being contaminated, disrupting ecological processes and aggravating the natural balance in the environment.

Solution of the problem of multipurpose use and conservation of water resources involves implementation of a number of measures designed to further reduce pollution and improve the quality of natural water sources. Among these are a variety of hydrotechnical measures involving modernization of existing and creation of new types of hydrotechnical structures to provide the requisite technology for improving the quality of wastewater being discharged by industrial and agricultural concerns, for preventing erosion, and for controlling the inflow of corrosive and toxic waters into natural sources.

The general hydrotechnical structures now in use do not always satisfy the standards placed on water storage facilities due to the specific features of their operation.

For instance, a spillway dam in a water storage complex must simultaneously create a storage basin and contribute to artificial aeration of the water being released over it; i.e., function as a treatment plant.

In general hydrotechnical structures, the requisite conditions are as follows: smooth connection of bays, smooth flow around barriers, steady fluid flow, etc. In water storage facilities, on the other hand, it is necessary to strive toward creation of turbulent flows, maximum circulation, and connection between bays consisting of cascade drops, falls, and races.

In special water storage facilities, it is necessary to provide for joint operation of structures with organisms. Thus, for instance, a common regulator must include screens populated by microorganisms or algae that are capable of absorbing harmful impurities, or a filter wall with a prepared

horizontal biofilter for simultaneous detention and purification of the discharge, etc.

Considering the specifics of operation of water storage facilities, the simple transfer of design solutions for general hydrotechnical structures to the structures of water storage complexes cannot be regarded as correct.

Thus, for instance, earth and earth-rock dams, and flood plain levees, which in water storage complexes are situated on foundations that are very weak in terms of load-carrying capacity, have a flattened profile which increases the hours involved in their construction and also draws out construction periods. Construction of heavy concrete spillway structures on earth dams is often quite difficult.

The problem of water storage facilities can be solved through extensive use of synthetic fabrics and structures manufactured from them. Widespread adoption of flexible structures will considerably reduce the time needed for putting into operation those structures required for efficent water quality control, will aid in uniformly redistributing the burdens of industrial capacities, having freed up colossal facilities and traditional materials (concrete, reinforced concrete, brick, asbestos cement, ceramics, cast iron, steel, glass), simplify assembly, disassembly, operation of structures, and greatly reduce capital investments as well as operating and transportation costs.

The important properties of flexible structures that favorably distinguish them from traditional hydrotechnical structures are as follows: adaptability for industrial production, simplicity, mobility, portability, easy assembly, hydrophily, thermal stability, low susceptibility to biollogical and chemical damage, corrosion resistance, and compatibility with automatic control systems.

The most important property of flexible structures lies in their being designated "flexible;" i.e., readily adaptable to external stresses; one and the same structure, under specific conditions, can function as an automatic gate, aerator, or check structure.

Flexible structures, because of their flexibility and elasticity, are capable of being adapted to complex natural situations and have a great influence in terms of containing elemental disasters in case of floods and mudflows, restoring the banks of artificial ponds, lakes, and seas, regression and aggression of the sea, reclaiming aquifers and diverting fresh water into an assigned region, and preventing water and wind erosion.

It is important to note here that through the use of flexible structures, it is possible to solve a number of problems within the larger question of conserving water resources within a much shorter period of time and at only a fraction of the previous cost. This is substantiated by domestic and foreign experience in operating flexible structures.

Experience in the use of synthetic fabrics and polymer films for check, conveyance, regulating, and seepage-control structures in hydrotechnical projects, with the most advanced design properties and most profitable service lives, has proved that domestic and foreign work in this direction is progressing rapidly and has stepped beyond the boundary of experimental adoption.

The economic benefit derived from using synthetic materials and structures made from them, the considerable reduction in construction times, and the relative simplicity of their manufacture, installation, and disassembly form the basis for their ever increasing adoption by hydraulic engineering.

It is believed extensive adoption of synthetic fabrics and polymer films by hydrotechnical construction is not a goal in itself, but rather an economically substantiated factor. The economic effectiveness of using fundamentally new materials in hydraulic engineering for comprehensive solution to the problem of protecting the environment consists not only in more extensive elimination of harmful substances and occurrences from the water cycle and prevention of erosion processes, although this is very important, but also in saving hundreds of millions of rubles worth of human and natural resources. It must not be forgotten that successful solution of the problem, of preserving nature, demands development of protective measures for entire watersheds, not just individual portions of water sources.

The comprehensive scientific approach to the problem of conserving water resources and improving their application and erosion-control measures by applying the achievements of scientific and technical thought to an entire watershed will make it possible to improve and regenerate water resources and terminate or eliminate erosion. It will have an inestimable influence on the course of communist construction.

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GLOSSARY

The purpose of compiling the glossary is to standardize terminology and define the meanings of the respective concepts. In developing the glossary, special attention was given to new terms for describing lightweight hydraulic structures using polymer materials.

The selection of terms has been made on the basis of encyclopedias, dictionaries, lists of recommended terms, literature on scientific methodology, and scientific and technical literature.

The glossary is in English and Russian. Equivalent terms can be found by using the numbering system.

1. Basic Definitions

1.1 **Hydraulic structure** — A structure designed for using the water resource.

1.2 **Water intake structure** — A structure for water intake from a natural or constructed reservoir.

1.3 **Spillway structure** — A structure for discharging excess water.

1.4 **Shell** — A body bounded by two surfaces, the distance between which is small in comparison with the other dimensions of the body.

1.5 **Flexible shell** — A shell made of materials having high tensile strength but without the ability to withstand any other type of stress (compression, bending, shear).

1.6 **Elastic reinforcement** — A rod with the ability to withstand tension only.

1.7 **Stay line** — A structural element (cable, rope, wire strand, etc.).

2. Design of Flexible and Elastic Structures

2.1 **Mechanics** — The science of the mechanical interactions of material bodies.

2.2 **Statics** — The branch of mechanics that deals with equilibria in mechanical systems on which forces are acting.

3. Anchored Hydraulic Structures

3.1 **Membrane structure** — An open, anchored shell stabilized by the water-pressure gradient; supporting stay lines (stayed trusses) are used only at the edges of the shell.

3.2 **Membrane-anchored structure** — A closed or open, anchored shell in which the impermeable membrane and the stay lines work together.

3.3 **Anchored structure** — A closed or open, anchored shell in which the membrane acts mainly as a seepage control device while the whole load is borne by a system of stay lines or by netting.

3.4 **Anchored firmed structure** — A shell that is prestressed or stabilized by excess pressure of the fill medium which, after taking on its intended shape, is then firmed by means of freezing, spraying with shotcrete or concrete mixes, or grouting of the shell with cementitious materials.

3.5 **Anchored combination structure** — A structure made up of a system of stay lines, rigid structural elements acting in flexure or compression, and an impermeable membrane made of synthetic materials or plastic-coated sheet metal.

3.6 **Multilevel anchored structure** — A structure comprised of inflatable flexible anchored shells arranged one atop another.

3.7 **Multishell anchored structure** — A structure comprised of inflatable anchored shells in a nested arrangement.

3.8 **Multisectional anchored structure** — A structure comprised of anchored shells arranged one next to another.

3.9 **Arch-type anchored structure** — A structure having positive (not prestressed) or negative (prestressed) Gaussian curvature.

4. Earth-Polymer Structures

4.1 **Earth-polymer structure** — A structure made of local and noncohesive soils to which the properties necessary for hydrotechnical structures (impermeability and stability) are imparted with the help of polymer materials.

4.2 **Inflatable (encapsulated) earth-polymer structure** — A structure in which a prestressed closed shell is filled with soil in order to impart the intended shape and load-carrying capacity to the shell.

4.3 **Reinforced earth-polymer structure** — A structure made of reinforced soil whose free surfce is reinforced with polymer or other impermeable materials.

4.4 **Reinforced earth** — Earth consisting of granular particles, with a flexible reinforcing framework, longitudinal with respect to the applied forces, the noncohesive soil being retained by friction directly against the longitudinal reinforcing framework.

4.5 **Compacted earth-polymer structure** — A structure made of polymer materials and local soil which, after taking on its intended shape, is firmed by freezing, spraying with shotcrete, plastic, or a similar mix, and grouting with cementitious materials*.

4.6 **Combined earth-polymer structure** — A structure made by adding flexible earth-polymer elements and rigid elements performing compressive or flexural functions.

5. Regulating Devices Using Polymer Materials

5.1 **Flexible regulating device** — A device whose main working part is constructed by the use of flexible materials and which is intended to maintain some parameter constant.

5.2 **FIRD [Flexible inflatable (encapsulating-type) regulating device]** — A device whose main part takes the form of a closed, elastic cavity.

5.3 **MFRD (Membrane-type flexible regulating device)** — A device whose main part takes the form of an open, flexible shell.

5.4 **CIRD (Combined-type flexible regulating device)** — A device whose main part includes an elastic shell and rigid elements working together with the elastic shell.

5.5 **MIRD (Mixed-type inflatable regulating device)** — A device whose main part is a combination of membrane, shells, encapsulated shells, and combined-type shells.

5.6 **FHORD (Flexible hydraulically operated regulating device)** — A regulating device operated by flowing water.

5.7 **Flexible power-operated regulating device** — A regulating device in which additional energy sources are used to maintain some parameter (level, discharge, etc.) constant.

5.8 **Angle of combined regulating device** — Using maximum possible gate elevation angle at which the flexible cord turns into a straight line.

6. Laminated Shell Structures

6.1 **Flexible laminated hydraulic structure** — A structure that includes several interconnected shells whose operation ensures the functioning of the whole structure.

6.2 **Vertical laminated structure** — A structure in which a change in the number of shells in operation alters mainly the vertical dimensions of the structure; that is, its height.

6.3 **Horizontal laminated structure** — A structure in which a modification in the number of shells in operation alters chiefly the horizontal dimensions of the structure; that is, its design configuration.

6.4 **Nested horizontal laminated structure** — A horizontal multishell structure in which shells are placed one inside another; that is, according to the "matrioshka" doll principle.

6.5 **Externally arranged laminated horizontal structure** — A structure in which shells are placed next to each other.

6.6 **Pressure-inflated laminated flexible structure** — A structure whose functioning is ensured by pressure feeding of a filler agent (liquid, gas, or mix) into the cavities of shells through the operation of power devices, such as pumps or compressors.

6.7 **Self-inflating laminated structure** — A structure in which the inflation of shells and through it the operation of the structure are ensured by the flow in which the structure is placed.

6.8 **Combination laminated inflatable structure** — A structure of which part is comprised of self-inflating shells while the remainder is of pressure-inflated shells.

6.9 **Flexible, laminated hydraulic shell structure** — A structure whose component shells are closed to form cavities and a filler is introduced to make the structure operational.

6.10 **Membrane laminated, flexible hydraulic structure** — A structure whose component shells are open and sail-shaped.

6.11 **Combination laminated flexible hydraulic structure** — A structure of which some components are inflatable shells while the remainder are membrane shells.

6.12 **Layered, laminated flexible hydrotechnical structure** — A structure whose shell is reinforced by a system of stay lines through a series of horizontal, longitudinal lines, thus

*The word for "spraying" appears to be out of place in the original text, coming before "mixtures" instead of as given in the translated text.

forming curvilinear sections of strips on the surface of the structure.

7 Fishways and Their Structural Elements

7.1 **Combination fishway** — A structure made of traditional materials and flexible shells, allowing fish to pass through barriers in one or two directions.

7.2 **Combination fishway** — A fish passage made of traditional materials with flexible structural elements which serves to permit fish movement by either controlled or uncontrolled methods.

7.3 **Fishway with uncontrolled fish movement** — A lightweight fish handling facility which allows fish to move independently from one pool to another.

7.4 **Partly controlled fishway** — A fish ladder allowing fish to move in two directions through cascade locks.

7.5 **Cascade lock method** — A method by which fish pass from pool to pool through successive transfer from basin to basin according to the principle of ship locks.

7.6 **Fishway with controlled passage** — A structure regulating the movement of fish from pool to pool.

7.7 **Escalator-type fishway** — A structure for controlled movement of fish in which the functional parts are flexible shells that create a traveling wave effect.

7.8 **Escalator-type fishway** — A fish passage which controls the movement of fish through the use of flexible moving shells that attract fish to indpendent movement.

7.9 **Controlled cascade fishway** — A structure for the passage of fish through cascade locks, combined with controlled fish movement.

7.10 **Crest gates** — Sections of the flexible shells of an escalator-type fishway that rise above the bottom as the movable structural elements are deflected.

7.11 **Space between crests** — That portion of an escalator-type fishway structure bounded by a pair of crest gates.

7.12 **Resting pools** — The space between crests containing the medium (water, fish) moving in the desired direction.

7.13 **Escalator-type fish elevator** — A fish ladder consisting of a feeder canal in the form of a vertical or inclined shaft which is divided into a number of moving chambers with peristaltic walls (i.e., successive waves of contractions passing along the walls).

7.14 **Moving chamber with peristaltic walls** — A section of an escalator-type fish elevator bounded by inflatable elastic diaphragms.

7.15 **Peristaltic walls** — The moving parts of an escalator-type fish elevator, designed as a series of inflatable elastic diaphragms which are pressurized as the fish pass along.

7.16 **Inflatable elastic diaphragm** — Inflatable flexible shells of various designs, which control the cross section shutoff of the vertical or inclined shaft of a fish elevator or other conduit.

7.17 **Simulation device** — Elastic moving elements in a fish passage whose surfaces have artificial coatings of pebbles, gravel, and vegetation.

7.18 **Fish passage lock** — A fishway enabling fish to pass through cascade locks.

7.19 **Revolving fish holding tank** — A part of a fish passage lock, representing a combination gate with fish-shocking gear.

7.20 **Fish accumulation eddy zone** — Artificially generated eddies with a vertical axis of rotation, for the purpose of concentrating fish in one area.

7.21 **Effective range of a revolving fish holding tank** — A wedge of water bounded by the screen of a combination-type gate and fish-shocking gear.

7.22 **Combination-type gate** — A flexible structure that includes a rigid screen and a flexible shell forming a closed, inflatable vessel.

7.23 **Fishway lock with fish-attracting flow layers** — A fish protection structure with a working chamber and a fish holding tank, in which the flow is divided by a transparent synthetic fabric into separate layers having independent hydraulic regimes.

7.24 **Independent hydraulic regime** — A fish-attracting flow to the fish holding basin, held constant within one layer and not depending on adjacent layers.

7.25 **Fishway lock with traveling intake** — A fish passage with a movable chamber shuttling between fish holding tanks that move in a planar direction.

7.26 **Stationary elastic fish holding tank** — A part of a fishway lock with reinforced concrete bulkheads and a middle part made up of flexible structural elements.

7.27 **Mobile flexible fish holding tank** — A part of a fishway lock made of flexible structures with adjustable horizontal and vertical surfaces.

7.28 **Flexible working chamber** — A part of a fishway structure made of flexible supporting structural elements.

7.29 **Elastic (flexible) supporting element** — A structure made of flexible materials, forming the main structural element absorbing various loads.

7.30 **Fishway dam** — A flexible hydraulic structure of the combined type, permitting the damming of backwater while simultaneously allowing fish to pass through over the entire length of the barrier.

7.31 **Fishway and adjoining structure** — A flexible hydraulic structure with the combined function of a fishway.

7.32 **Controlled eel passage** — A structure with a flexible device for controlled movement of breeding eels from the lower to the upper pool.

7.33 **Fishway plus spillway system** — The portion of a fishway and adjoining structure built in the form of elastic ponds and connected with one another in series.

7.34 **Water discharge slots** — Openings to allow the withdrawal of part of the discharge of a transit flow in a fishway-spillway system to improve the performance of the structure.

7.35 **Prefabricated section of a fishway** — A part of a fish passage assembled from standardized sections of flexible shells.

7.36 **Pond-type flexible fishway** — A fish passage for the independent movement of fish, including a section made up of elastic ponds.

7.37 **Flexible adjoining structure** — A flexible, combination-type device which operates as a regulating structure for the entry of fish to the fish ladder at the river bottom.

7.38 **Automated fish-attracting flow system** — A self-adjusting flexible complex structure ensuring constant fish-attracting flow intake velocities to the fishway structure.

7.39 **Gate for multilayer fish-attracting flow** — A traditional slide gate with gate-valve openings covered by flexible valves having variable geometric fish-attracting flow velocities in a fish holding tank.

7.40 **Felxible valves with variable geometrical shapes** — Inflatable flexible shells of various designs ensuring a uniform distribution of the multilayer fish-attracting flow velocities in a fish holding tank.

7.41 **Fish pass gate** -- The traditional gates of spillway dams (slide or radial), with thin-walled fish holding and transfer devices built into their cavities, used to hold and rapidly transfer fish from pool to pool.

7.42 **Thin-walled fish holding and transfer device** — A rotating hollow cylindrical structural element of a fish pass gate with a flexible shell.

7.43 **Flexible active-function shells** — The elastic structural elements of a fish protection structure, representing their working units.

7.44 **Flexible shells with passive function** — Stationary elastic elements of a fish protection structure.

7.45 **Power-operated flexible structures** — Flexible shells of various designs for lifting, moving, and other purposes.

7.46 **Flexible fish-shocking gear** — An elastic structure inducing fish to move independently through a fish ladder.

7.47 **Variable cross section float-in openings** — Apertures in the barriers across the fishway, intended for the passage of fish and controlled by means of power-operated inflatable structures or inflatable elastic diaphragms.

7.48 **Relief-simulating inflatable structures** — Flexible panels and shells that provide additional conditions for attracting fish by simulating the bottom relief or the bank outline.

7.49 **Set of fish-attracting factors** — The combination of favorable hydraulic, biological, and physiological conditions for attracting and moving fish.

7.50 **Principal attractants** — The hydraulic conditions that provide attractive velocities throughout the fishway structure and at its entrance which exclude disturbed flows in the structure and at its outlet.

Terms for Engineering Artificial Spawning Grounds, Spawning Channels, and Their Structural Elements

7.51 **Mobile life-support systems** — Flexible structures serving as artificial spawning grounds, having auxiliary control devices to set up favorable hydraulic and physiological conditions for the spawning, growth, and movement of fish.

7.52 **Hydropneumosubstrate** — An artificial substrate created by covering the body of a flexible shell with gravel or algae.

7.53 **Height regulating device** — An inflatable or combination-type flexible structure used to vary the submergence depth of a spawning

field, mobile fish holding tank, or other structure.

7.54 **Flexible anchored structure** — An inflatable (encapsulated) membrane or combination-type flexible structure used to hold an object on the bottom or at a given depth in a reservoir.

7.55 **Antisilting system** — A flexible structure that prevents silting of artificial spawning grounds or sections of a reservoir, thus making it possible to clean the spawning grounds without raising them to the surface.

7.56 **Fish resettling facility**— A flexible structure of transparent texture and other elastic fabric, with protective devices to prevent fish larvae from being eaten by predators, making it possible in some part of the basin to resettle the population of a species that had disappeared.

7.57 **Fish spawning, feeding, and stocking facility** — A flexible, usually an all-purpose flexible structural element forming an indispensable part of resettling facilities and mobile life-support systems.

7.58 **Flexible spawning channel** — An artificial channel-type spawning ground made of elastic sections in which both the gradient of the bottom and the hydraulic regime can be controlled.

7.59 **Prefabricated (portable) pond** — An artificial flowthrough tank of the membrane, inflatable, or combined type which is placed in a reservoir or on a bank and is used for fish management purposes.

7.60 **Fish removal and migration flume** — A fillable or dual-purpose structure of the channel type, intended for the removal of fish from hazardous zones and their transport in a desired direction (by the mobile fish protection system of a fishway structure).

7.61 **Areal protective inflatable structure** — A structure usually made of flexible shells, designed to protect the habitats of a given species of fish from the action of waves, pollution, and so forth.

7.62 **Inflatable fish barrier** — An active or passive function flexible shell that restrains or guides fish by physiological, mechanical, or hydraulic means or a combination of them.

7.63 **Mechanical flexible fish barrier** — A barrier created a flexible panels of various designs blocking the path of fish into a hazardous zone.

7.64 **Hydraulic flexible fish barrier** — A flexible structure creating a hydraulic barrier to the movement of fish into a hazardous zone.

7.65 **Physiological flexible fish barrier** — Flexible, inflatable shells of various designs creating a physiological barrier to the movement of fish into a hazardous zone.

7.66 **Multipurpose flexible fish barriers** — Chiefly flexible multipurpose structures which form barriers to the movement of fish into a hazardous zone through the combined action of physiological, mechanical, and hydraulic factors.

7.67 **Flexible hydraulic structures and devices used in the construction of ecological systems** — A group of flexible hydraulic structures for the purpose of preserving and complementing the environment (water) and the living things (fish).

8. Seepage Control Structures of Synthetic and Polymer Materials

8.1 **Flexible seepage control structures (aprons, bank abutments, seepage control barriers)** — Structural elements made of synthetic and polymer materials (rubberized fabric, film-fiber, and film) with great deformative ability and designed to reduce the danger of seepage flow affecting hydraulic structures, cut down the loss of water through seepage, and protect ground water from pollution by seepage flow from reservoirs.

8.2 **Flexible, flat seepage control device** — An elastic panel placed directly on a soil foundation or under a protective layer.

8.3 **Flexible, inflatable soil-encapsulated seepage control structure** — A closed elastic shell with laminated profile, filled with soil or any other local material.

8.4 **Combination seepage control structures** — Structures made by combining flexible elemens with rigid ones.

8.5 **Flexible aprons** — Aprons, made of synthetic and polymer materials, that deform in accordance with the deformation of the foundation.

8.6 **Flexible nondeforming aprons** — Aprons that have the original shape of the underground contour the structure had after its completion.

8.7 **Flexible deforming aprons** — Aprons that alter the shape of the underground contour as the foundation is deformed by the action of seepage and surface flows.

8.8 **Flexible deformed aprons** — Aprons that, after deformation of the foundation has ceased, acquire the stable, altered shape of the underground contour.

8.9 **Flexible bank abutment** — An adjoining device made of an elastic polymer material, which is placed on the bank slopes and does not absorb the lateral pressure of the backfill, or else is used as a retaining wall and does absorb the soil pressure.

8.10 **Flexible bank abutments acting as retaining walls** — Tension-stressed membranes fastened to the soil either directly by an extension of the membrane itself or by anchoring devices.

8.11 **Flexible seepage control barriers (membranes, cutoff curtains, diaphragms, protective linings)** — Seepage control elements of hydraulic structures, made of synthetic and polymer materials.

8.12 **Surface (unburied) seepage control membranes or open linings** — Devices placed on top of the soil foundation and made of elastic materials with higher resistance to atmospheric effects and aggressive media.

8.13 **Buried seepage control membranes** — Devices placed under a protective soil layer.

8.14 **Film membrane** — Surface seepage control devices made of film materials.

8.15 **Soil-film membranes** — Buried seepage control devices made of film materials.

8.16 **Concrete and film membranes** — Combination seepage control devices made of film materials and protected on top by concrete and reinforced concrete slabs.

8.17 **Flexible diaphragms** — Vertical or inclined seepage control barriers in the form of flat panels of elastic material.

8.18 **Flexible cutoff curtains** — Seepage control bariers in the form of a continuous row of individual shells made of elastic material and filled with water or soil.

9. Water Conveyance Structures

9.1 **Flexible water conveyance structures** — Structures in which the main element is a flexible shell, forming a channel through which liquid can be transported over obstacles without significant elevation differences.

9.2 **FMWC (Flexible membrane water conveyance) structures** — Structures in which the design shape of the channel is maintained by the interaction between the membrane shell and the beams, forms, struts, cables, or cable networks.

9.3 **FIWC (Flexible inflatable water conveyance) structures** — Structures in which the design shape of the channel is maintained by inflating the side shells with a pressurized filling agent (air, soil, water, water-air mixture, etc.).

9.4 **FCWC (Flexible combination-type water conveyance) structures** — Structures in which the design shape of the channel is maintained by the interconnection between the membrane shell filled with traditional materials and the inflated side shells containing a pressurized filler, or else by the combined action of the membrane and the inflatable side shells.

9.5 **Flexible water conveyance regulating structure** — Structures that make it possible to regulate the flow regime by changing the shape of the cross seciton.

9.6 **Flexible water conveyance structure** — A structure in which the design shape of the channel is maintained by interaction with the flow.

9.7 **Flexible pipelines** — Water conveyance structures in which the liquid flow is bounded on all sides by a flexible shell (the walls of the pipline), indpendent of the liquid discharge rate.

9.8 **Shape coefficient of a membrane-type water conveyance structure** — A dimensionless quantity that characterizes the cross-seciton shape at maximum permissible flow and is equal to the ratio between the top width of the flume channel and the perimeter of the shell.

10. Other Reference

10.1 *Plastics in Hydrotechnical Construction*, A Joint Effort of U.S./U.S.S.R. Teams in Plastic Films and Soil Stabilizers, Plastic Piping Systems for Irrigation and Drainage, and Polymer Concrete.

10.1 Пластмассы в гидротехническом строительстве, коллективная работа рабочих групп СССР и США по Пластмассовым пленкам и стабилизаторам грунта, Пластмассовым трубопроводам для орошения и осушения, и Полимербетонам.

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Введение.

Цель разработки глоссария – унификация терминологии и уточнение содержания соответствующих понятий.

Особое внимание при разработке уделялось новым терминам, используемым при описании облегченных гидротехнических конструкций с использованием полимерных материалов.

При определении состава терминов использовались энциклопедии, словари, сборники рекомендуемых терминов, научно-методическая и научно-техническая литература.

I. Основные определения.

I.I. Гидротехническое сооружение – сооружение, служащее для использования водных ресурсов или для борьбы с вредными действиями воды.

I.2. Водозаборное сооружение – сооружение, возводимое для забора воды из естественного или искусственного водоёма.

I.3. Водосбросное сооружение – сооружение для сброса излишков воды.

I.4. Оболочка – тело, ограниченное двумя поверхностями, расстояние между которыми мало по сравнению с остальными его размерами.

I.5. Мягкая оболочка – оболочка, изготовленная из материалов, обладающих высоким сопротивлением растяжению, но не способная сопротивляться каким-либо иным видам напряжённого состояния (сжатию, изгибу, сдвигу).

I.6. Гибкая нить – стержень, способный сопротивляться только растяжению.

I.7. Ванта – конструктивный элемент (трос, канат, проволочная прядь и т.д.).

2. Расчёт мягких и гиоких конструкций.

2.I. Механика – наука о механических взаимодействиях материальных тел.

2.2. Статика – раздел механики, в котором изучаются условия равновесия механических систем под действием сил.

3. Гидровантовые конструкции.

3.I. Меморанные конструкции – незамкнутые гидровантовые оболочки, стаоилизированные перепадом давлений воды: ,несущие ванты (вантовые фермы) имеются только по краям оболочек.

3.2. Меморанные вантовые конструкции – замкнутые или незамкнутне гидровантовые оболочки, где водонепронецаемая мембрана и ванты работают совместно.

3.3. Вантовые конструкции – замкнутые или незамкнутые гидровантовые оболочки, где мембрана выполняет главным ооразом функции противофильтрационного материала.а всю нагрузку воспринимает вантовая система или сетка.

3.4. Гидровантовые отверждаемые конструкции – предварительно напряженные или стаоилизированные избыточным давлением заполнителя оболочки, которые после принятия проектной формы отверждаются замораживанием, набризгом бетона и ему подобных смесей или иньекцией ь оболочку связующих материалов.

3.5. Гидровантовые комоинированные конструкции – конструкции, выполненные из системы вант, жёстких элементов, работающих на изгиб или сжатие, и водонепроницаемой мембраны в виде синтетических материалов или листового металлопласта.

3.6. Гидровантовые многоярусные конструкции – кон – струкции, выполненные из гидровантовых оболочек, установленных одна над другой.

3.7. Гидровантовые многооболочковые конструкции –кон-

струкции, выполненные из гидровантовых оболочек, установленных одна в другой.

3.8. Гидровантовые многосекционные конструкции – конструкции, выполненные из гидровантовых оболочек, установленных одна около другой.

3.9. Арочные гидровантовые конструкции – конструкции положительной или отрицательной гаусовой кривизны, соответственно предварительно ненапряжённые и предварительно напряженные.

4. Грунтополимерные конструкции.

4.1. Под грунтополимерными конструкциями следует понимать конструкции, выполненные из местных и несвязных грунтов, которым придаются необходимые для гидротехнических сооружений свойства (водонепроницаемость, устойчивость) с помощью полимерных материалов.

4.2. Наполняемыми грунтополимерными конструкциями называются такие, в которых предварительно напряжённая замкнутая оболочка заполнена грунтом для придания ей проектной формы и несущей способности.

4.3. Армированные грунтополимерные конструкции – конструкции, выполненные из армированного грунта, свободная поверхность которого укрепляется полимерными или иными водонепроницаемыми материалами.

4.4. Армированный грунт – грунт, образованный зернистыми частицами с гибкой, продольной относительно действующих сил арматурой и где несвязный грунт удерживается непосредственным трением с продольной арматурой.

4.5. Отверждаемые грунтополимерные конструкции –конструкции, выполненные из полимерных материалов и местного грунта, который после принятия конструкцией проектной формы отверждается замораживанием бетона, пластмасс или им подобных, нагнетанием смесей или инъекцией связующих компонентов.

4.6. Комбинированными грунтополимерными конструкциями следует называть конструкции, выполненные с применением мягких грунтополимерных и жёстких элементов, работающих на сжатие или изгиб.

5. Регуляторы с применением полимерных материалов.

5.1. Мягкий регулятор - устройство, основной рабочий орган которого выполнен с использованием гибких материалов, предназначенное для поддержания какого-либо параметра постоянным.

5.2. Мягкий регулятор наполняемого типа (МРНТ) - устройство, основной рабочий орган которого выполнен в виде замкнутой гибкой оболочки-ёмкости.

5.3. Мягкий регулятор мембранного типа (МРМТ) - устройство, основной рабочий орган которого выполнен в виде незамкнутой гибкой оболочки-ёмкости.

5.4. Мягкий регулятор комбинированного типа (МРКТ) - устройство, основной рабочий орган которого включает гибкую оболочку и жёсткие элементы, работающие совместно с гибкой оболочкой.

5.5. Мягкий регулятор смешанного типа (МРСТ) - устройство, основной рабочий орган которого выполнен в виде комбинаций мембранных, наполняемых и комбинированных оболочек.

5.6. Мягкий регулятор гидравлического действия (МРГД)- регулятор, работающий на энергии водного потока.

5.7. Мягкий регулятор принудительного действия - регулятор, в котором для поддержания какого-либо параметра (уровень, расход и т.д.) постоянным, используются дополнительные источники энергии.

5.8. Раскройный угол регулятора комбинированного типа- максимально возможный угол поднятия затвора, при котором

гибкая нить вырождается в прямую линию.

6. Многооболочковые мягкие конструкции.

6.1. Многооболочковой мягкой гидротехнической конструкцией называется конструкция, имеющая в своём составе несколько взаимосвязанных оболочек, функционирование которых обеспечивает работоспособность всей конструкции.

6.2. Многооболочковая конструкция вертикального типа характеризуется тем, что изменение числа работающих оболочек в основном вызывает изменение вертикальных размеров конструкции, т.е. её высоты.

6.3. Многооболочковая конструкция горизонтального типа характеризуется тем, что маневрирование числом работающих оболочек вызывает изменение преимущественно горизонтальных размеров конструкции, т.е. ее плановых очертаний.

6.4. Многооболочковая конструкция внутреннего горизонтального типа характеризуется расположением оболочек одна в другой, т.е. по принципу матрёшки.

6.5. Многооболочковая конструкция горизонтального внешнего типа характеризуется расположением оболочек по принципу одна к одной.

6.6. Многооболочковая мягкая конструкция принудительного наполнения характеризуется тем, что работоспособность конструкции обеспечивается путём принудительной подачи заполнителя (жидкости, газа или смеси) в полости оболочек за счёт работы силовых установок, типа насосов или компрессоров.

6.7. Самонаполняемая многооболочковая конструкция характеризуется тем, что процесс заполнения оболочек и придание, тем самым, работоспособности конструкции обеспечивается за счет энергии потока, в котором конструкция установлена.

6.8. Многооболочковая конструкция смешанного наполне-

ния характеризуется тем, что одна часть конструкции представлена самонаполняемыми оболочками, а другая часть - оболочки принудительного заполнения.

6.9. Многооболочковая мягкая гидротехническая конструкция называется наполняемой тогда, когда составляющие её оболочки выполнены замкнутыми с образованием полостей, когда с целью придания конструкции рабочей способности подаётся заполнитель.

6.10. Многооболочковая мягкая гидротехническая конструкция называется мембранной, если составляющие её оболочки выполнены разомкнуто в виде паруса.

6.11. Многооболочковая мягкая гидротехническая конструкция называется комбинированной, если одна часть оболочек, входящих в её состав, представлена наполняемыми, а другая мембранными оболочками.

6.12. Многооболочковая мягкая гидротехническая конструкция называется ярусной, в случае если оболочка сооружения закрепляется системой связей по ряду горизонтальных продольных образующих с образованием на поверхности сооружения криволинейных участков ярусов.

7. Рыбопропускные сооружения и их элементы.

7.1. Рыбопропускное сооружение комбинированного типа- сооружение, выполненное из традиционных материалов и мягких оболочек, служащее для пропуска рыб через препятствие в одном (двух) направлении (ях).

7.2. Рыбоход комбинированного типа - рыбопропускное сооружение, выполненное из традиционных материалов с элементами мягких конструкций, служащее для управляемого и неуправляемого способа транспортировки рыб.

7.3. Рыбоход с неуправляемым процессом транспортирования - рыбопропускное сооружение лёгкого типа, обеспечивающее самостоятельное передвижение рыб из одного объ-

фа в другой.

7.4. Рыбоход с частично управляемым транспортированием – рыбопропускное сооружение, осуществляющее пропуск рыб в двух направлениях методом каскадного шлюзования.

7.5. Метод каскадного шлюзования – способ перевода рыб из бьефа в бьеф посредством последовательно-поочерёдного перевода из бассейна в бассейн по принципу шлюзования судов.

7.6. Рыбопропускное сооружение с управляемым процессом транспортирования – сооружение, осуществляющее принудительный перевод рыб из бьефа в бьеф.

7.7. Рыбопропускное сооружение эскалаторного типа – сооружение с управляемым процессом транспортирования рыб, в котором рабочим органом являются мягкие оболочки, создающие эффект бегущей волны.

7.8. Рыбоход эскалаторного типа – рыбопропускное сооружение с управляемым процессом транспортирования рыб посредством стимулирования их к самостоятельному движению мягкими подвижными оболочками.

7.9. Рыбопропускное сооружение каскадно-управляемого типа – сооружение для пропуска рыб методом каскадного шлюзования, совмещённого с управляемым процессом транспортирования.

7.10. Гребни-затворы – участки мягких оболочек рыбопропускного сооружения эскалаторного типа, возвышающиеся над его дном по мере перемещения подвижных элементов.

7.11. Межгребневое пространство – участок рыбопропускного сооружения эскалаторного типа, ограниченный парой гребней-затворов.

7.12. Транспортный бассейн – межгребневое пространство с находящейся в нём транспортируемой средой (вода, рыба), перемещающейся в нужном направлении.

7.13. Рыбоподъёмник эскалаторного типа – рыбопропускное сооружение, состоящее из подводящего канала верти-

кальной или наклонной шахты, разделённой на ряд перемещающихся камер с заглатывающими стенками.

7.14. Перемещающаяся камера с заглатывающими стенками – участок рыбоподъёмника эскалаторного типа, ограниченного эластичными наполняемыми диафрагмами.

7.15. Заглатывающие стенки – рабочий орган рыбоподъёмника эскалаторного типа, выполненный в виде серии наполняемых эластичных диафрагм, находящихся под давлением по мере продвижения рыб.

7.16. Наполняемая эластичная диафрагма – наполняемые мягкие оболочки различного конструктивного исполнения, обеспечивающие регулируемое перекрытие сечения вертикальной или наклонной шахты рыбоподъёмника или иного трубопровода.

7.17. Заглатывающий рабочий орган – эластичные подвижные элементы в рыбопропускных сооружениях с нанесёнными на поверхность искусственным покрытием в виде галек, гравия, растительности.

7.18. Рыбоходный шлюз – рыбоход, осуществляющий пропуск рыб методом ступенного шлюзования.

7.19. Поворотная рыбонакопительная ёмкость – рабочий орган рыбоходного шлюза в виде затвора комбинированного типа с побудительным устройством.

7.20. Водоворотно-аккумулирующая зона – искусственно созданные водовороты с вертикальной осью вращения с целью концентрации в них рыб.

7.21. Зона действия поворотной рыбонакопительной ёмкости – часть воды, ограниченная щитом затвора комбинированного типа и побудительным устройством.

7.22. Затвор комбинированного типа – комбинированная гибкая конструкция, включающая жёсткий щит и мягкую оболочку, образующую заглубленную наполняемую ёмкость.

7.23. Рыбопропускной шлюз с послойным извлечением – рыбопропускное сооружение с рабочей камерой и рыбонако-

нителем, поток в котором разделён прозрачной синтетической тканью на слои, в пределах которых создаётся автономный гидравлический режим.

7.24. Автономный гидравлический режим – режим привлекающего потока рыбонакопителем, устанавливаемый постоянным в пределах одного слоя и не зависящий от режима смежных слоёв.

7.25. Рыбопропускной шлюз с блуждающим входом – рыбопропускное сооружение с рабочей камерой, связанной подвижно с перемещающимися в плане рыбонакопителями.

7.26. Стационарный гибкий рыбонакопитель – часть рыбопропускного шлюза с железобетонными оголовками и средней частью, выполненной из гибких элементов.

7.27. Мобильный гибкий рыбонакопитель – часть рыбопропускного шлюза из мягких конструкций с регулируемым планово-высотным обоснованием.

7.28. Гибкая рабочая камера – часть рыбопропускного сооружения, выполненная из гибких несущих элементов.

7.29. Гибкий (мягкий) несущий элемент – конструкция, выполненная из гибких (мягких) материалов и являющаяся основным элементом, воспринимающим комплекс нагрузок.

7.30. Рыбоход – плотина – мягкое гидротехническое сооружение комбинированного типа, обеспечивающее поддержание подпора с одновременным пропуском рыб по всему перегораживаемому фронту.

7.31. Рыбоходно-сопрягающее устройство – мягкое гидротехническое сооружение с совмещёнными функциями рыбопропускного и сопрягающего устройств.

7.32. Угреход с управляемым процессом транспортирования – сооружение с гибким устройством для принудительного перемещения производит. угрей из нижнего в верхний бьеф.

7.33. Рыбоходно-водосливной тракт – тракт рыбоходно-сопрягающего сооружения, выполненний в виде эластичных

прудков, последовательно сообщающихся друг с другом.

7.34. Расходоотборные щели – отверстия, предусматривающие отбор части расхода транзитного потока рыбоходно-водосливного тракта с целью улучшения работы сооружения.

7.35. Складывающаяся секция рыбохода – часть рыбопропускного сооружения, собранного из типовых секций мягких оболочек.

7.36. Мягкий рыбоход прудкового типа – рыбопропускное сооружение для самостоятельного продвижения рыб, включающее тракт, выполненный из эластичных прудков.

7.37. Гибкое сопрягающее устройство – мягкое, комбинированного типа, служащее для регулированного сопряжения входа в рыбопропускное сооружение с дном реки.

7.38. Система автоматизированного привлечения – самонастраивающаяся мягкая комплексная конструкция, обеспечивающая поддержание постоянства привлекающих скоростей на входе в рыбопропускное сооружение.

7.39. Затвор послойного привлечения – традиционный плоский затвор с клинкетными отверстиями, перекрываемыми геометрически изменяемыми мягкими клапанами.

7.40. Геометрически изменяемые мягкие клапаны – наполняемые мягкие оболочки различной конструкции, обеспечивающие равномерность распределения привлекающих скоростей в рыбонакопителе с послойным привлечением.

7.41. Рыбопропускной затвор – традиционные затворы водосливных плотин (плоские, сегментные) с устроенными в их полости тонкостенными накопительно-переводящими устройствами, служащими для накопления и быстрого перевода рыб из бьефа в бьеф.

7.42. Тонкостенное накопительно-переводящее устройство – вращающийся полый цилиндрический элемент рыбопропускного затвора, включающий мягкую оболочку активного типа.

7.43. Мягкие оболочки активного типа – эластичные элементы рыбоохранных сооружений, являющиеся рабочим орга-

ном.

7.44. Мягкие оболочки пассивного типа – эластичные неподвижные элементы рыбоохранных сооружений.

7.45. Силовые мягкие конструкции – мягкие оболочки различного конструктивного исполнения с функциями механизмов подъёма, перемещения и т.д.

7.46. Мягкое побудительное устройство – эластичное устройство, стимулирующее рыб к самостоятельному продвижению по рыбопропускному сооружению.

7.47. Щелевые отверстия переменного сечения – отверстия в устройствах, перегораживающих тракт рыбопропускного сооружения, предназначенные для прохода рыб, регулируемые посредством мягких силовых конструкций или наполняемых эластичных диафрагм.

7.48. Рельефоэмитирующие мягкие конструкции – мягкие полотнища и оболочки, обеспечивающие дополнительные условия привлечения на основе копирования рельефа дна или очертания берегов.

7.49. Комплекс привлекающих факторов – совокупность благоприятных гидравлических, биологических и физиологических условий привлечения и транспортирования рыб.

7.50. Основные условия привлечения – гидравлические условия, обеспечивающие по всему тракту рыбопропускного сооружения и на его входе привлекающие скорости, которые исключают вихревые течения в тракте рыбопропускного сооружения и на его выходе.

Термины инженерных искусственных нерестилищ, нерестовых каналов и их элементов.

7.51. Мобильные комплексы жизнеобеспечения – мягкие конструкции искусственных нерестилищ, с вспомогательными регулирующими устройствами, создающими благоприятные гидравлические и физиологические условия для икрометания, выращивания и транспортирования рыб.

7.52. Гидро-пневмосубстрат – искусственный субстрат, создаваемый за счёт выполнения рабочим телом мягкой оболочки с нанесённым на неё покрытием в виде гравия или водорослей.

7.53. Высотно-регулирующее устройство – наполняемая или комбинированная мягкая конструкция, служащая для изменения глубины погружения нерестового поля, мобильного рыбонакопителя и т.д.

7.54. Мягкое анкерное устройство – наполняемая, мембранная или комбинированная мягкая конструкция, служащая для удержания объекта на дне или заданной глубине водоёма.

7.55. Система антизаиливания – мягкая конструкция, служащая для предотвращения заиливания нерестовых искусственных полей или участков водоёма, позволяющая без подъёма на поверхность очищать нерестовые поля.

7.56. Реакклиматизационное устройство – мягкое сооружение из светопрозрачной и другой эластичной ткани с защитными мероприятиями от поедания личинок хищниками, позволяющее восстанавливать в какой-либо части водоёма популяции исчезнувшего вида.

7.57. Нересто-кормовое вырастное устройство – мягкое сооружение, преимущественно мягкая конструкция универсального назначения, являющаяся неотъемлемой частью реакклиматизационных устройств и мобильных комплексов жизнеобеспечения.

7.58. Мягкий нерестовый канал – искусственное нерестилище канального типа, выполненное из эластичных секций с регулируемым уклоном дна и гидравлическим режимом соответственно.

7.59. Сборно-разборный (передвижной) пруд – искусственный проточный водоём мембранного, наполняемого или комбинированного типа, установленный в водохранилище или на берегу и предназначенный для использования в рыбохо-

зяйственных целях.

7.60. Рыбоотводящий транспортный лоток – наполняемая или комбинированная конструкция каналового типа, предназначенная для отвода рыб из опасных зон и транспортировки их в нужном направлении (мобильным комплексом жизнеобеспечения рыбопропускного сооружения).

7.61. Ареалозащитные мягкие конструкции – сооружения, выполненные преимущественно из мягких оболочек, предназначенные для защиты областей обитания данного вида рыб от воздействия волн, загрязнения и т.д.

7.62. Мягкое рыбозаградительное сооружения – активные и пассивные мягкие оболочки, обеспечивающие задержание или направление рыб на основе физиологического, механического, гидравлического или комплексного воздействия.

7.63. Мягкое рыбозаградительное сооружение механического действия – препятствия, создаваемые мягкими полотнищами различных конструкций на пути движения рыб в опасную зону.

7.64. Мягкое рыбозаградительное сооружения гидравлического действия – мягкие конструкции, создающие гидравлические препятствия на пути движения рыб в опасную зону.

7.65. Мягкое рыбозаградительное сооружение физиологического действия – мягкие наполненные оболочки различной конструкции, создающие физиологические препятствия на пути движения рыб в опасную зону.

7.66. Мягкое рыбозаградительное сооружение комплексного назначения – преимущественно мягкие конструкции комбинированного типа, создающие препятствия на пути движения рыб в опасную зону в виде комплексного воздействия физиологических, механических и гидравлических факторов.

7.67. Мягкие гидротехнические сооружения и устройства инженерно-экологических комплексов – группа мягких гидротехнических сооружений природоохранного назначения, находящаяся в обратной связи с живыми объектами (рыбой) и

окружающей средой (водой).

8. Противофильтрационные устройства из синтетических и полимерных материалов.

8.1. Гибкие противофильтрационные устройства (флютбеты, береговые устои, противофильтрационные преграды) - элементы сооружений, выполненные из синтетических и полимерных материалов (резино-тканевых, плёночно-тканевых и плёночных), обладающих большой деформативной способностью и предназначенные для снижения опасности воздействия фильтрационного потока на гидротехническое сооружение, уменьшения потерь воды на фильтрацию и защиты подземных вод от загрязнения фильтрующимися из хранилищ стоками.

8.2. Гибкие плоские противофильтрационные устройства - конструкции, представляющие собой эластичное полотнище, укладываемое непосредственно поверх грунтового основания или под защитный слой.

8.3. Гибкие грунтонаполняемые противофильтрационные устройства - конструкции, представляющие собой замкнутую эластичную оболочку распластанного профиля, заполненную грунтом или любым другим местным материалом.

8.4. Комбинированные противофильтрационные устройства-конструкции, выполненные путём сочетания гибких элементов с жёсткими.

8.5. Гибкие флютбеты - флютбеты, деформирующиеся в соответствии с деформациями основания и выполненные из синтетических и полимерных материалов.

8.6. Гибкие недеформированные флютбеты - флютбеты, имеющие первоначальную форму подземного контура, которая была у сооружения после его возведения.

8.7. Гибкие деформирующиеся флютбеты - флютбеты, изменяющие форму подземного контура в процессе деформаций основания, наблюдаемых в результате действия фильтрационного и поверхностного потоков.

8.8. Гибкие деформированные флютбеты – флютбеты, получившие после прекращения деформаций основания устойчивую изменённую форму подземного контура.

8.9. Гибкие береговые устои – сопрягающие устройства из эластичных полимерных материалов, укладываемые на откосы берега, не воспринимая боковое давление грунта засыпки, или служащие в качестве подпорных стенок, воспринимающих давление грунта.

8.10. Гибкие береговые устои, играющие роль подпорных стенок – напряжённо-растянутые мембраны, закреплённые в грунте непосредственно продолжением самой мембраны или с помощью анкерных устройств.

8.11. Гибкие противофильтрационные преграды (экраны, завесы, диафрагмы, защитные облицовки) – конструкции гидротехнических сооружений из синтетических и полимерных материалов, используемые в качестве устройств, препятствующих фильтрации.

8.12. Поверхностные (непогребенные) противофильтрационные экраны или открытые облицовки – устройства, укладываемые поверх грунтового основания и выполняемые из эластичных материалов, обладающих повышенной атмосферостойкостью, стойкостью к агрессивным средам.

8.13. Погребённые противофильтрационные экраны – устройства, укладываемые под защитный слой грунта.

8.14. Плёночные экраны – поверхностные противофильтрационные устройства, выполненные из плёночных материалов.

8.15. Грунто-плёночные экраны – погребённые противофильтрационные устройства, выполненные из плёночных материалов.

8.16. Бетонно-плёночные экраны – комбинированные противофильтрационные устройства, выполненные из плёночных материалов и защищённые сверху бетонными и железобетонными плитами.

8.17. Гибкие диафрагмы – вертикальные или наклонённые противофильтрационные преграды в виде плоского полотнища из эластичного материала.

8.18. Гибкие завесы – противофильтрационные преграды в виде непрерывного ряда отдельных оболочек из эластичного материала, наполняемых водой или грунтом.

9. Водопроводящие сооружения. Терминология.

9.1. Мягкие водопроводящие сооружения – сооружения, основным элементом которых является мягкая оболочка, из которой выполнено русло, обеспечивающее транспортирование жидкости преодолевая препятствия без значительной разности отметок уровней.

9.2. Мягкие мембранные водопроводящие сооружения (ММВС) – сооружения, проектная форма русла которых обеспечивается за счёт взаимодействия мембранной оболочки и балок, форм, стоек, тросов или тросовых сеток.

9.3. Мягкие наполняемые водопроводящие сооружения – (МНВС) – сооружения, проектная форма русла которых обеспечивается за счёт наполнения бортовых оболочек находящихся под изонточным давлением заполнителя (воздух, грунт, вода, водновоздушная смесь и т.д.).

9.4. Мягкие комбинированные водопроводящие сооружения (МКВС) – сооружения, проектная форма русла которых обеспечивается путём взаимосвязи мембранной оболочки с традиционными материалами и наполненных бортовых оболочек, находящихся под изонточным давлением заполнителя, или за счёт совместной работы мембраны и наполняемых бортовых оболочек.

9.5. Мягкие регулирующие водопроводящие сооружения – сооружения, позволяющие регулировать режим потока путём изменения формы поперечного сечения.

9.6.Мягкие водопроводящие сооружения гидравлического действия – сооружения, проектная форма русла которых обеспечивается при взаимодействии с транспортирующим потоком.

9.7.Мягкие трубопроводы – водопроводящие сооружения, в которых поток жидкости ограничен со всех сторон мягкой оболочкой (стенками трубопровода) независимо от величины расхода жидкости.

9.8.Коэффициент формы мембранного водопроводящего сооружения – безразмерная величина, характеризующая форму поперечного сечения при максимально допустимом наполнении и равная отношению ширины лотка-канала по верху к периметру оболочки.

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When Congress authorized the reclamation of arid and semiarid lands in the West with the Reclamation Act of 1902, the Secretary of the Interior established the Reclamation Service within the United States Geological Survey. In 1907, the Reclamation Service became an independent agency within the Department of the Interior. By action of the Secretary of the Interior in 1923, the Reclamation Service became the Bureau of Reclamation. In November 1979, the name was changed to the Water and Power Resources Service by Secretarial Order, and in May 1981, the Secretary of the Interior changed the agency's name back to the Bureau of Reclamation.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.